Patterns and Risk Factors for Injuries and Shoulder Muscular Activation in Dogs performing Agility Tasks.

by

Kimberley L. Cullen

A Thesis presented to The University of Guelph

In partial fulfillment of requirements for the degree of Doctorate of Philosophy in Biophysics

Guelph, Ontario, Canada

© Kimberley L. Cullen, January, 2014
Canine agility competition, one of the fastest growing canine sports worldwide, is a performance sport in which dogs and their handlers work as a team to navigate a sequence of obstacles. Dogs perform tasks that include jumping, weaving, making tight turns in tunnels, climbing ramps and seesaws, and moving on and off of, or across elevated surfaces while being timed for speed and scored for faults. A retrospective electronic survey was used to understand the pattern of injuries (chapter 2) and to investigate potential risk factors for injury (chapter 3) among dogs participating in agility competitions. Results from these studies were used to focus a biomechanical investigation quantifying the muscular activation of four shoulder muscles (Biceps Brachii, Triceps Brachii – Long Head, Supraspinatus, and Infraspinatus) during specific agility-related tasks identified as being associated with a high risk of injury in the sport (chapter 5). To facilitate this investigation, we present specific guidelines regarding the placement of fine-wire electromyography electrodes and data collection/normalization procedures to enable investigations of muscle activation during dynamic activities (chapter 4).
ACKNOWLEDGEMENTS

“I can no other answer make, but, thanks, and thanks.”
~William Shakespeare

To my advisor, mentor, protector, fiercest supporter, and now my friend, Dr. James Dickey, I owe my deepest and sincerest appreciation. I am fairly certain this dissertation would not have been written without your direct involvement. It still gives me chills to think back on that first day so long ago, in your (very cluttered) lab space, when we met for the first time. Yours was not the first office I walked into to share my vision, my passion and my dream to turn it into a dissertation, but it was most definitely the last. Remembering back on hearing you say, that not only did you think it was a worthwhile project to pursue, but that you would help pave the way to make it happen, always brings me close to tears. Jim, your patient teaching and mentoring, your unwavering support of my work, my ideas, my tuition, and of me, will always be treasured and cherished. If I can pay forward just a fraction of the opportunities you afforded me, I would see this as a great success.

“Appreciation is a wonderful thing: It makes what is excellent in others belong to us as well.”
~Voltaire

To my co-advisors: Drs. Stephen Brown and Leah Bent, thank you both for agreeing to join Jim & me on this crazy adventure. Your seamless entries onto the team and your willingness to help lead the charge in these untested waters were greatly appreciated. The thoughtful guidance and endless encouragement you provided, along with those offered by the rest of my advisory committee, Drs. Jeff Thomason and Noël Moens, were tremendously valuable and insightful. To all of you, your time and efforts will always be remembered and truly appreciated.

To Dr. Stephanie Nykamp, your expert guidance on all matters related to ultrasound, anatomy and electrode insertion was invaluable to the success of these projects. Your creative trouble-shooting prowess, your attention to detail, and your willingness to work unconventional hours to help me see this through, make me your number one fan.

For their help in spreading the word about the agility injury survey used in the first two projects, I am indebted to the support from Mr. Greg Derrett, UK Agility, the Agility Association of Canada and Ms. Susan Garrett of Say Yes Dog Training.

To Dr. Sheilah Hogg-Johnson, who provided statistical guidance and help with survey development and to Dr. Jason Coe, who offered support for survey development, your assistance helped in immeasurable ways (and not simply because there are no points for comparison we could use in this regard).
To the graduate students that assisted in various ways, from helping with data coding, data collection and even building the testing equipment, I owe my thanks: Mr. Jarrod Shugg, Mr. Ryan Frayne, Mr. Robert Caryn, Mr. Andrew Dragunas, Ms. Leila Kelleher, and Mr. Peter Wegscheider, you’re all good people. Thank you for your time, energy and in some cases – quite literally - your blood, sweat and tears.

To my friends in the agility community who stepped up to provide me with jumps and the materials to construct the A-frame obstacle – Ms. Deryl Drysdale, Mrs. Sarah Hughes of Details Dog Training, Ms. Darlene Woz of Rubber on the Run and Ms. Rochelle Hall Bagwell of American Recycling – Thank you most sincerely. Your good deeds will not go unpunished and I fully expect the agility gods will shine on you in the ring in the future!

“Dogs are not our whole life, but they make our lives whole.”
~Roger Caras

To my four-legged companions, past, present, and future, thank you for introducing me to and sharing my passion for the sport of agility. You inspire me with your talent and dedication. You are the best teammates a girl could hope for, but more importantly, you are excellent teachers. To all of the dogs that played a role in the generation of knowledge from this body of work, I owe my debt of gratitude. Your efforts have contributed to the growing body of evidence that can help us make this sport safer for all to play. For that, I say ‘good dog’.

“I have found the best way to give advice to your children is to find out what they want and then advise them to do it.”
~Harry S. Truman

To my parents, Brian & Lynn: You have taught me the value of love, honesty, kindness and generosity. You placed great importance on education and lifelong learning and you encouraged me to be captivated by wonder and moved by the mysterious. For that I am, and will forever be, most grateful.

“Other things may change us, but we start and end with the family.”
~Anthony Brandt

To my husband John: your patience, love and understanding are without end. You have given me the greatest gifts of all: the freedom to reach for the stars, the belief that I cannot fail and the faith that you’ll always catch me when I should I fall. You are, most definitely, the unsung hero in this journey.

To my children, Ryan & Kenzie: you have shown me the real meaning of life. You have taught me to be present in every moment, to laugh with abandon, to be bold, to use my imagination and to not allow my perceptions to limit my reality. You may still be too little to understand how important you were in helping me see this project all the way to the end, but know this – I couldn’t have done it without you! I hope to be able to repay you this service, all the days of the rest of my life.
# TABLE OF CONTENTS

## CHAPTER ONE

<table>
<thead>
<tr>
<th>GENERAL INTRODUCTION</th>
<th>REFERENCES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

## CHAPTER TWO

**INTERNET-BASED SURVEY OF THE NATURE AND PERCEIVED CAUSES OF INJURY TO DOGS PARTICIPATING IN AGILITY TRAINING AND COMPETITION EVENTS**

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>INTRODUCTION</th>
<th>MATERIALS AND METHODS</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>13</td>
<td>16</td>
</tr>
</tbody>
</table>

Sample

Survey instrument and procedures

Statistical analysis

RESULTS

Characteristics of handlers and dogs

Injury characteristics

DISCUSSION

REFERENCES

31

## CHAPTER THREE

**SURVEY-BASED ANALYSIS OF RISK FACTORS FOR INJURY AMONG DOGS PARTICIPATING IN AGILITY TRAINING AND COMPETITION EVENTS**

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>ABBREVIATIONS</th>
<th>INTRODUCTION</th>
<th>MATERIALS AND METHODS</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>43</td>
<td>43</td>
<td>45</td>
</tr>
</tbody>
</table>

Sample

Survey instrument and procedures

Data analysis

RESULTS

DISCUSSION

51

## CHAPTER FOUR

**FEASIBILITY OF COLLECTING FINE-WIRE ELECTROMYOGRAPHIC RECORDINGS IN FOUR CANINE SHOULDER MUSCLES DURING HIGHLY DYNAMIC TASKS**

<table>
<thead>
<tr>
<th>ABSTRACT</th>
<th>ABBREVIATIONS</th>
<th>INTRODUCTION</th>
<th>METHODS</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>64</td>
<td>65</td>
<td>68</td>
</tr>
</tbody>
</table>

Participants

Method of recruitment and consent

Electromyography

Electrode preparation

Skin Preparation

Ultrasonographic Examination
Electrode Insertion 70
Kinematic Parameters 71
Video Camera 71
Accelerometer 71
Harness 71
Procedures 72
  Phase 1: Establishing fEMG insertion protocol. 72
  Phase 2: Establishing fEMG data collection protocol with research dogs. 73
  Phase 3: Establishing fEMG data collection protocol with client-owned dogs. 74
Data Analysis 75
  EMG Signal Collection and Processing 75
  Identifying individual strides 76
  EMG Normalization 76
RESULTS AND DISCUSSION 77
  Phase 1: Establishing fEMG insertion protocol. 77
  Phase 2: Establishing fEMG data collection protocol with research dogs. 78
  Phase 3: Establishing fEMG data collection protocol with agility dogs. 79
CONCLUSIONS 82
REFERENCES 83

CHAPTER FIVE 94

AN INVESTIGATION TO QUANTIFY MUSCULAR ACTIVATION OF FOUR CANINE SHOULDER MUSCLES IN DOGS PERFORMING TWO AGILITY-SPECIFIC TASKS. 94

ABSTRACT 95
ABBREVIATIONS 96
INTRODUCTION 96
METHODS 100
  Participants 101
  Method of recruitment and consent 101
  Electromyography 102
    Electrode preparation 102
    Skin Preparation 102
    Ultrasonographic Examination 102
    Electrode Insertion 103
  Video Camera 103
  Harness 104
Data Management and Analysis 105
  EMG Signal Collection and Processing 105
  Stride Normalization 105
  Amplitude Normalization 106
  Defining Individual Strides 106
Descriptive and Statistical Analyses 108
  1. Descriptive Analysis of Muscle Activity 108
  2. Differences in Muscle Activity across Agility-specific Tasks 108
  3. Differences in Muscle Activity between Contact Performance when Descending the A-frame 109
RESULTS 109
  1. Descriptive Analysis of Muscle Activity 110
LIST OF TABLES

CHAPTER TWO

TABLE 1 34
Selected characteristics of 1,669 agility dog handlers that participated in a 2009 survey to identify patterns of injuries (ie, type and severity of injury and affected region of the body) among dogs participating in agility training and competition events and examine associations between these patterns and perceived causes of injury.

TABLE 2 35
Results of Chi-square analysis for first-reported injuries incurred by dogs (n = 1,209) during agility competitions or practice sessions and number of injuries classified as mild or severe for each obstacle.

CHAPTER THREE

TABLE 1 61
Selected characteristics of dogs that did (n = 1,209) or did not (2,592) incur injuries during agility-related activities as reported by 1,669 agility dog handlers from 27 countries in a 2009 Internet-based survey.

TABLE 2 62
Unadjusted and adjusted ORs (95% CIs) of risk factors for injury among the same dogs as in Table 1 (n=3404, dogs with missing data were excluded from this analysis).

CHAPTER FOUR

TABLE 1 88
Electrode placement. Electrodes were positioned in the center of the mediolateral dimension of the muscle and a specific distance measured from the anatomical landmark (in cm) in the longitudinal direction. Depth of electrode insertion within the muscle relative to transverse plane is also indicated (in cm).
CHAPTER FIVE

TABLE 1 130

Frequency distribution of usable fEMG recordings (n=384) by participant, muscle site, stride event, agility-specific task, and contact performance type. In each comparison, the total number of available fEMG recordings are represented.

TABLE 2 131

Mean peak muscle activation for the TBLH, BB, SP, and IF muscles for the pre-transition (stride-1), transition (stride_0) and post-transition stride (stride_1) events for each agility-specific task.
CHAPTER TWO

FIGURE 1 37
Common anatomic sites of mild (dark gray) and severe (light gray) injuries incurred by dogs during agility-related activities as reported by handlers in a 2009 internet-based international survey. Responses were received from 1,669 handlers regarding 3,801 dogs; 1,602 injuries were described for 1,209 dogs. A labeled diagram was provided to enable consistent reporting of affected body regions. Handlers could select multiple anatomic sites if applicable for each injury incident. Mild injuries were defined as those that resolved in < 1 month, and severe injuries required ≥ 2 months to resolve (according to the handlers’ responses). Confirmation of reported injuries by a veterinarian was not required. Seventy-nine of 1,602 injuries involving 127 anatomic sites were excluded from analysis because recovery was not complete or recovery time was not clear. Regions classified as other included injuries to the tail.

FIGURE 2 38
Common types of mild and severe injuries incurred by the same dogs as in Figure 1. Sprains were defined as ligament injuries and strains were defined as muscle or tendon injury. Injuries classified as other were reported by handlers in their own words in open-ended text fields and included herniated disk (n = 24) arthritis (12), jammed toes (8) or joints (4), nerve injury (8), bone spur (4), dental injury (3), concussion (3), unspecified hernia (3) lumbosacral stenosis (2), joint capsule injury (2) and 1 each of unspecified brain injury, sesamoiditis, bee sting, cauda equina injury, cold or limber tail syndrome, fibrocartilaginous embolism, and spondylosis. Handlers could select multiple types of injury for a given injury incident. Seventy-nine of 1,602 injuries involving 103 types of injury were excluded from analysis because recovery was not complete or recovery time was not clear. See Figure 1 for remainder of key.

FIGURE 3 39
Common anatomic sites for first-reported injuries attributed to the 3 most common causes of agility-related injury (ie, those resulting from interactions with a bar jump [black bars], A-frame [light gray bars], or dog walk [white bars]) for the same dogs as in Figure 1. Results of Pearson χ² goodness-of-fit analyses indicated significant differences from expected equal injury distribution for several anatomic sites across the 3 most common causes of agility-related injury. *P < 0.05. †P < 0.01.

FIGURE 4 40
Common types of injuries attributed to the 3 most common causes of agility-related injury for the same dogs as in Figure 1. Results of Pearson χ² goodness-of-fit analyses indicated significant differences from expected equal injury distribution for injury type across the 3 most common causes of agility-related injury. *P < 0.05. †P < 0.01. See Figures 2 and 3 for key.
CHAPTER FOUR

FIGURE 1 90

Technique for using ultrasound to visualize and intramuscular fine-wire electrode placement. Triceps Brachii – Long Head (TBLH) is shown as an example. An ultrasound image of the location of the needle in the muscle belly (see Arrows), using B-mode, real-time ultrasonography (8 MHz micro-convex transducer, GE Healthcare Logiq P5 Ultrasound System). All needle insertions were performed by a board certified veterinary radiologist with expertise in musculoskeletal ultrasonography.

FIGURE 2 91

The final modified Ruffwear Web Master™ Harness (size Small, Ruffwear, Oregon USA) that was used for securing the wireless fEMG transducers to the dog without interfering with electrode placement. The ribcage strapping was removed and adjusted into a neck strap and the length of material covering the shoulder regions was trimmed back to prevent interference with the electrode insertion sites. Elastic strapping was sewn onto the top of the harness to hold the transducers and four separate hook and loop closure Velcro straps were attached to the harness to help keep the wires from becoming tangled together and to provide strain relief for the wires between the insertion sites and the wireless transducers.

FIGURE 3 92

Computed tomography dorsal reformatted images with a maximum intensity projection thick slab technique (1 cm thickness), documenting the majority of the path and the tip of the fine wires during Phase 1 testing of our fine-wire electrode insertion attempts into the four shoulder muscles of interest: A. TBLH, B. BB, C. SP, and D. IF muscles. All insertions shown were made using 1.5”, 27.5 gauge hypodermic needles. The location of the electrode insertions were confirmed as appropriate for the TBLH, SP, and IF muscles. The insertion of the BB electrode (Figure 3B) shows that our attempt was unsuccessful. The length of the needle used for these insertions was determined to be too short to adequately insert the BB electrodes into the muscle bellies. Additional attempts using a 2” needle were confirmed as successful upon dissection (not shown).

FIGURE 4 93

Ensemble-averaged fEMG recordings of all four shoulder muscles comparing the pre-testing (red lines) and post-testing (blue lines) walking trials for a representative dog; A: TBLH, B: BB, C: SP, and D: IF muscles. The gait cycle is presented in percent of stride, from the initiation of left forelimb floor contact to the subsequent ipsilateral forelimb paw strike. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance.
CHAPTER FIVE

FIGURE 1

Ensemble-averaged fEMG recordings of all four shoulder muscles observed during the post-experiment walking trials for a representative dog; A: TBLH, B: BB, C: SP, and D: IF. The gait cycle is presented in percent of stride, from the initiation of left forelimb floor contact to the subsequent ipsilateral paw strike. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. ST = Stance Time and SW = Swing Time.

FIGURE 2

Ensemble-averaged fEMG recordings of all four shoulder muscles: TBLH, BB, SP, and IF for the 1st jump pre-transition strides (stride-1), transition strides (stride_0) and post-transition strides (stride_1) and the 2nd jump pre-transition strides (also stride_1), transition strides (stride_5) and post-transition strides (stride_6) during the jumping task for a representative dog. The still frame images at the top of the figure provide a visual snapshot of each stride in the series for the jumping task. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. When no shaded line appears, it indicates that there was only one performance trial available for this stride event. ST = Stance Time and SW = Swing Time.

FIGURE 3

Ensemble-averaged fEMG recordings of all four shoulder muscles: TBLH, BB, SP, and IF for the pre-transition strides (stride-1), transition strides (stride_0) and post-transition strides (stride_1) during the Ascending A-frame – High Apex height task for a representative dog. The still frame images at the top of the figure provide a visual snapshot of each stride in the series for the ascending A-frame task. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. ST = Stance Time and SW = Swing Time.

FIGURE 4

Ensemble-averaged fEMG recordings of all four shoulder muscles: TBLH, BB, SP, and IF for the pre-transition strides (stride-1), transition strides (stride_0) and post-transition strides (stride_1) during the Ascending A-frame – Low apex height task for a representative dog. The still frame images at the top of the figure provide a visual snapshot of each stride in the series for the ascending A-frame task. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. ST = Stance Time and SW = Swing Time.
CHAPTER FIVE

FIGURE 5  138

Ensemble-averaged fEMG recordings of all four shoulder muscles: TBLH, BB, SP, and IF for the pre-transition strides (stride-1), transition strides (stride_0) and post-transition strides (stride_1) during the Descending A-frame – High apex height task for a representative dog. The still frame images at the top of the figure provide a visual snapshot of each stride in the series for the descending A-frame task. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. ST = Stance Time and SW = Swing Time.

FIGURE 6  139

Ensemble-averaged fEMG recordings of all four shoulder muscles: TBLH, BB, SP, and IF for the pre-transition strides (stride-1), transition strides (stride_0) and post-transition strides (stride_1) during the Descending A-frame – Low apex height task for a representative dog. The still frame images at the top of the figure provide a visual snapshot of each stride in the series for the ascending A-frame task. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. ST = Stance Time and SW = Swing Time.

FIGURE 7  140

Interaction plots for the comparison of the average Peak EMG amplitudes for each of the agility specific tasks (d_high, d_low, j_Na, u_high, u_low) by stride event type (pre-transition stride, stride-1; transition stride, stride_0; and post-transition stride, stride_1) for all four muscles: A. TBLH, B. BB, C. SP, D. IF.

FIGURE 8  141

Interaction plots for the comparison of the average Peak EMG amplitudes for the jumping task (transition strides for jump 1: stride_0 and for jump 2: stride_5) based on the number of pre-strides taken before each jump (i.e., zero, one or two strides taken before lift-off) for all four muscles: A. TBLH, B. BB, C. SP, D. IF. For Jump 1, there are zero stride data points as several dogs chose to lift off directly from a sit into the transition stride. This did not occur for the second jump, all dogs in the sample added at least one stride between landing from the first jump before taking off for the second jump.

FIGURE 9  142

Interaction plot for the comparison of the average Peak EMG amplitudes for the two Descending A-frame post-transition strides (stride_1 for d_low and d_high) by contact performance type (run and stop) for the SP muscle which was statistically significant (p=0.03).
LIST OF ABBREVIATIONS

CI – Confidence interval
fEMG – fine-wire electromyography
BB – Biceps Brachii
SP – Supraspinatus
IF – Infraspinatus
TBLH – Triceps Brachii – Long Head
CT – Computed Tomography
CAF – Central Animal Facility
OVC – Ontario Veterinary College
CHAPTER ONE

GENERAL INTRODUCTION

Animal companionship is an integral component of life for many humans worldwide. We give names to our pets, we talk to them and play with them, we feed them our food, we take them to the doctor, we let them sleep with us in our beds and we mourn them when they die. Pet ownership is pervasive across many jurisdictions and dogs make popular pets. In Canada, 56% of households have at least one pet, with 43% of them owning a dog; and rates are similar in Australia (65% pet ownership with 40% owning a dog), the United States (60% pet ownership with 37% owning a dog), and the United Kingdom (52% pet ownership with 24% owning a dog). There is a growing body of evidence indicating that pet ownership comes with additional benefits for the human beyond just companionship, including improved physical, mental and emotional health.

Well-behaved dogs occupy a privileged place in their owner’s lives, who often go to great lengths to provide for their needs and desires. However, many dogs don’t fare as well, being abandoned to shelters or euthanized, because they exhibit behavioural problems (e.g., excessive barking, jumping up, destructive behaviour, etc.). Studies show that dogs that engage in obedience training exhibit fewer behavioural issues, are more compliant, and more often engage in shared activities with their humans.
There are a wide variety of shared activities that dogs and their humans can avail themselves of; running the gamut from a leisurely walk through the park before and after work, to specialized, organized and sanctioned events. These include breed conformation, obedience, agility, tracking, hunt trials, herding, Schutzhund, ring sport, sled dog racing, search and rescue, therapy dog work, draft-pulling, water rescue trials, lure coursing, earth dog work, flyball, and more.\textsuperscript{12–14}

One of these events, Agility, is fast becoming the most popular dog sport available worldwide.\textsuperscript{15} In 2012, the number of dog entries to sanctioned American Kennel Club (AKC) agility events was recorded at over 1.1 million, representing a growth rate of nearly 10\% annually over the last ten years.\textsuperscript{16} It is also a physically demanding sport for the dog, in which the dog and their handler work as a team to navigate a sequence of obstacles. Dogs perform tasks that include jumping, weaving, making tight turns in tunnels, climbing ramps and seesaws, and moving on and off of, or across elevated surfaces while being timed for speed and scored for faults.\textsuperscript{17–20} A recent physiological study looking at the hematologic and biochemical changes in dogs participating in agility events, found responses consistent with high intensity anaerobic exercise.\textsuperscript{21}

As there is in any sport, there is an inherent risk of injury to the canine participants. However to date, only limited information is available regarding injuries among dogs that participate in agility events. In 2009, Levy et al.\textsuperscript{22} conducted a survey limited to American agility dog handlers, and found that 33\% of the sample had been injured during agility training or competition. The most
commonly injured regions were the shoulder and back. Contact with an obstacle was reported as the perceived cause of injury, with A-frame, dog walk, and bar jump obstacles most commonly reported. Results of an earlier survey given to handlers attending the 2003 Ontario Regional Championships (Cullen, K., unpublished data) were consistent with those published by Levy and et al.\textsuperscript{22} Results gathered for 102 agility dogs attending this event indicated that 34\% of dogs had been injured from participation in the sport; the shoulder and back regions were the most common sites of injury and interaction with an A-frame was the most common perceived cause of injury.

As the popularity of canine agility competitions continues to grow, companion animal veterinarians may expect to see more patients that are injured while participating in this activity. In fact, clinical cases of shoulder injuries resulting from agility have been reported.\textsuperscript{23,24} Thus, understanding the etiology of such injuries is of critical importance. Although it is well understood that injury occurs when tissue loads exceed tissue tolerance, the link between reports of injury and causes or mechanisms is often elusive;\textsuperscript{25} one systematic framework suggests that it is important to first establish the incidence and severity of the injury problem and then establish the etiology and mechanism of injury through biomechanical studies;\textsuperscript{25} together these studies build a foundation for developing prevention strategies.\textsuperscript{25}

Biomechanical tools such as force plates, electromyography and motion-capture systems have been applied to study canine companion animals.\textsuperscript{26} Normal muscle function in healthy canines has been examined at a walk,\textsuperscript{27–29} at
a trot,\textsuperscript{30–34} and at a gallop.\textsuperscript{35} Several biomechanical studies have examined clinical canine populations including: partial and pancarpal arthrodesis,\textsuperscript{36} osteoarthritis,\textsuperscript{37–39} cranial cruciate ligament rupture\textsuperscript{40} and hip dysplasia.\textsuperscript{41,42}

However, limited research has evaluated the biomechanics of canine sport and agility.\textsuperscript{43–45} Researchers in the UK\textsuperscript{43} examined ground reaction forces in dogs performing different jumping tasks and observed high peak vertical forces in the forelimbs (4.5 times body weight) when dogs landed from a bar jump. To date, there have been no studies examining the biomechanics associated with performing the A-frame or dogwalk obstacles, which have been identified as potential risk factors for injury in previous work.\textsuperscript{22} Both of these obstacles require the dogs to run up an inclined surface and then transition to running full speed down the other side. Studies examining locomotion on sloped surfaces in quadrupeds\textsuperscript{46–51} and in humans\textsuperscript{52,53} suggest that we could expect the neuromuscular responses to differ for the dogs when ascending compared to descending these obstacles. However, these studies have primarily examined gait during walking\textsuperscript{46,48–53} or steady state trotting,\textsuperscript{47} and at slope angles less than 26 degrees.\textsuperscript{46,47,52,53} No data have been previously recorded in quadrupeds running while performing these tasks, and at angles comparable to the slope of the A-frame obstacle (i.e., between 38-40 degrees, depending on the jurisdiction).\textsuperscript{17–20}

The literature to date has emphasized the need to conduct studies to examine the prevalence and nature of agility-related injuries, to identify modifiable risk factors associated with an increased risk for injury in the sport and
to use this knowledge to understand more fully the biomechanical factors related to injury for specific agility tasks.

The objectives of the thesis were threefold: a retrospective electronic survey was used to understand the pattern of injuries (Chapter 2) and to investigate potential risk factors for injury (Chapter 3) among dogs participating in agility competitions. Results from these studies were used to focus a biomechanical investigation quantifying the muscular activation of four shoulder muscles (Biceps Brachii, Triceps Brachii – Long Head, Supraspinatus, and Infraspinatus) during specific agility-related tasks identified as being associated with a high risk of injury in the sport (Chapter 5). To facilitate this investigation, we present specific guidelines regarding the placement of fine-wire electromyography electrodes and data collection and normalization procedures to enable investigations of muscle activation during dynamic activities (Chapter 4). The results of this thesis have important implications to guide future research and prevention initiatives aimed at reducing agility-related injuries in dogs.
REFERENCES


CHAPTER TWO

This chapter has previously been published in the Journal of the American Veterinary Medical Association. It has been reprinted with permission.

Internet-based survey of the nature and perceived causes of injury to dogs participating in agility training and competition events

Kimberley L. Cullen, MSc; James P. Dickey, PhD; Leah R. Bent, PhD; Jeffrey J. Thomason, PhD; Noël M. M. Moens, MSc, DVM, DACVS

From the Biophysics Interdepartmental Group (Cullen, Dickey), the Department of Human Health and Nutritional Sciences, College of Biological Sciences (Bent), and the Departments of Biomedical Sciences (Thomason) and Clinical Studies (Moens), Ontario Veterinary College, University of Guelph, Guelph, ON N1G 2W1, Canada; the Institute for Work and Health, 481 University Ave, Toronto, ON M5G 2E9, Canada (Cullen); and the School of Kinesiology, Faculty of Health Sciences, University of Western Ontario, London, ON N6A 5B9, Canada (Dickey).

This manuscript represents a portion of a dissertation submitted by Ms. Cullen to the University of Guelph Biophysics Interdepartmental Group as partial fulfillment of the requirements for a Doctor of Philosophy degree.

Supported by the Ontario Veterinary College Pet Trust Fund. Ms. Cullen was also supported by a Natural Sciences and Engineering Research Council of Canada Graduate Scholarship.

None of the authors have any conflicts of interest to disclose regarding this manuscript.

The authors thank Susan Garrett for helping to disseminate the electronic survey to participants, Dr. Sheilah Hogg-Johnson for statistical guidance and survey development, Dr. Jason Coe for survey development, and Jarrod Shugg for data entry.

Address correspondence to Ms. Cullen (kcullen@iwh.on.ca).
ABSTRACT

Objective: To characterize injuries (ie, type and severity of injury and affected region of the body) among dogs participating in agility training and competition events and examine associations between injury characteristics and perceived causes of injury.

Design: Internet-based, retrospective, cross-sectional survey.

Animals: 3,801 privately-owned dogs participating in agility training or trials.

Procedures: A retrospective electronic survey was developed to investigate demographic factors for dogs and handlers, frequency of participation in agility training and competition, and perceived causes and characteristics of injuries acquired by dogs during agility-related activities. Respondents were handlers recruited through member lists of large canine agility associations in Canada and the United Kingdom and through promotion via an agility blog site. Associations between cause and anatomic site or type of injury and between injury severity (mild vs severe) and setting (competition vs practice) were investigated.

Results: Surveys were received from 1,669 handlers of 3,801 agility dogs internationally. Handler-reported data indicated 1,209 of 3,801 (32%) dogs had ≥ 1 injury; of 1,523 analyzed injuries, shoulder (349 injuries), back (282), and neck (189) regions and phalanges (202) were predominantly affected. Soft tissue injuries (eg, strain [muscle or tendon injury; 807], sprain [ligament injury; 312], and contusion [200]) were common. Injuries were most commonly incurred
during interactions with bar jumps, A-frames, and dog walk obstacles (260, 235, and 177 of 1,602 injuries, respectively). Anatomic site and type of injury were significantly associated with perceived cause of injury.

Conclusions and Clinical Relevance: These findings provide a basis for further experimental studies to identify specific mechanisms of various types of injury in dogs that participate in agility activities. (J Am Vet Med Assoc 2013;242:1010–1018)

INTRODUCTION

During agility competitions, dogs and their handlers work as a team to navigate a sequence of obstacles at speed, similar to show jumping in horse shows. A typical course includes 18 to 23 obstacles that involve jumping (ie, bar, panel, broad, spread, and tire jumps), weaving between upright poles, turning in tunnels (open and closed), climbing ramps (eg, A-frame) and seesaws, and movement on and off of, or across, other elevated surfaces (eg, dog walk and pause table); the type, number and sequence of obstacles varies substantially among competitions. Specifications for these obstacles can vary among different sponsoring organizations.1-3

Agility competition is rapidly becoming the most popular canine performance sport in the world.4 In North America, data indicate that the number of entries in American Kennel Club–sanctioned events in 2010 was close to 950,000, with a growth rate of nearly 10% annually between 2003 and 2010.5

The number of dogs newly registered to participate in Canada’s largest agility
organization, the Agility Association of Canada, also increased by approximately
10% per year from 2000 to 2010, with > 1,300 new registrations in 2010.\textsuperscript{a}

To date, only limited information is available regarding injuries among
dogs that participate in agility events. In 2009, Levy et al\textsuperscript{6} conducted a survey of
American agility dog handlers, with responses received for 1,627 dogs. They
found that 33\% of these dogs had been injured, with 58\% of injuries occurring
during agility competition. The most commonly injured regions were the shoulder
and back, and Border Collies appeared to incur a greater percentage of injuries
than did all other breeds. Contact with an obstacle was reported as the perceived
cause of injury, with A-frame, dog walk, and bar jump obstacles most commonly
reported. Results of a preliminary survey given to handlers attending the 2003
Ontario Regional Championships (Cullen, K., unpublished data) were consistent
with previously published\textsuperscript{6} findings. Results gathered for 102 agility dogs
attending this event indicated that 35 (34\%) had received an injury from
participation in the sport; the shoulder and back regions were the most common
sites of injury and interaction with an A-frame was the most common perceived
cause of injury. As the popularity of canine agility competitions continues to
increase, companion animal veterinarians may expect to see more patients that
are injured while participating in this activity; thus, understanding the etiology of
such injuries is of critical importance.

In recent years, the caliber of top-ranked dogs in the sport has risen
dramatically, with very small differences in scoring determining the winners at
prestigious world championship events; for instance, in an international agility
competition held in Louisville, Ky in 2011, course performance times among the
top 20 dogs in the qualifying round of the steeplechase event (which determined
eligibility into the $10,000 final steeplechase round) differed by < 1 second. In
response to the high degree of athletic ability of such dogs, judges are designing
more technically challenging courses, which increase the physical demands
placed on canine athletes and may potentially increase the risk of injury.
Although little is known about the implications that course design modifications
may have on this risk in dogs, there is a substantial body of evidence in the
equine literature to suggest that course design has a role in the risk of injury. In
steeplechase and cross country events, jump position (ie, angle and distance
between jumps), track surface, race distance, and speed are important factors
associated with serious injuries. Given the similarities among these sports,
despite the differences in species, it stands to reason that these factors may also
be associated with injury in dogs participating in agility training or competition.

Clearly, there is a need to expand on the knowledge base for better
assessment of the risk factors for injury among agility dogs. The objectives of the
study reported here were to characterize injuries (ie, type and severity of injury
and affected region of the body) incurred by dogs during agility training or
competition and to examine the associations between injury characteristics and
perceived causes of injury.
MATERIALS AND METHODS

Sample

Survey participants were handlers of agility dogs who had Internet access and were willing and able to complete an electronic survey in English. Respondents from any geographic location were eligible to complete the survey.

Survey instrument and procedures

A retrospective survey design was used to examine demographic information for handlers and dogs, frequency of participation in agility training and competitions, characteristics of any agility training- or competition-related injury, and factors perceived to cause or contribute to the injury. The survey instrument was based on a survey developed in a preliminary study, in which a group of handlers for 102 agility dog attending the Ontario Agility Association of Canada regional championship in 2003 answered questions regarding agility training- and competition-related injuries in their dogs (unpublished data). The final 27-item electronic survey was pretested with a small convenience sample of 10 agility dog handlers to ensure it was user-friendly and comprehensive before beginning participant recruitment for the present study. A copy of this e-survey can be found in Appendix 1. The survey instrument and research protocol were reviewed and approved by the University of Guelph Research Ethics Board.

The survey was initiated and responses provided between March 16 and September 30, 2009, were collected and analyzed. Participants were recruited
through member lists of large canine agility associations in Canada (Agility Association of Canada) and in the United Kingdom (UK Agility) and through promotion via an agility blog site. The electronic survey was promoted by these parties to their members once (via 1 contact/email address) on their websites, as well as on their Internet discussion lists and at local competitions.

Respondent participation was initiated by clicking on a website link that directly accessed the survey. Collection restrictions were placed on the survey (on the basis of internet protocol address) to ensure that only 1 survey/respondent could be completed. Respondents were not blinded to the purpose of the study. There was an opportunity for respondents with multiple dogs to provide answers for each dog separately. Additionally, if a dog had incurred multiple injuries, respondents were instructed to fill out separate forms for each injury (up to 5 injuries/dog).

Demographic information collected included geographic location and the handler’s gender and age. The number of dogs that the handler had entered in agility competitions during his or her career, number of years of experience in agility training, number of trials participated in during the past year, and frequency of agility practice for the handler were solicited, as well as any preventative measures intended to keep dogs fit for agility activities and whether the handler and dogs participated in other canine sports. Information collected for dogs included breed, height at the withers (ie, highest point of the shoulders), weight, date of birth, number of years of participation in agility activities, agility associations for which the dog was registered, and whether any agility training-
or competition-related injuries had been incurred. Results of analysis of risk factors for injury among these same dogs were reported elsewhere.\textsuperscript{14}

If applicable, handlers were asked to provide their best estimate regarding the type of injury, anatomic region affected, and perceived cause of injury. Confirmation of reported injuries by a veterinarian was not a requirement for participation in this study.

A labeled diagram was provided to aid in consistent reporting of affected body regions. Regions were labeled (without demarcation of specific anatomic boundaries) as follows: head, mouth or teeth, eye, neck, chest (rib cage), back (shown as the dorsum extending approximately from the highest point of the shoulders to the lumbar spine), flank (lateral aspect of the abdomen caudal to the rib cage), loin (dorsal region between the back and the croup), croup (dorsal aspect of the hindquarters), shoulder (scapular region), upper arm (brachium), forearm (antebrachium), elbow joint, carpal joint, upper and lower thigh (regions of the hind limb proximal to the stifle joint and between the stifle and tarsal joints, respectively), stifle joint, patella, tarsal joint, metacarpus, metatarsus, phalanges of the forelimbs or hind limbs, footpads, tail, or other.

For type and cause of injury, several response options were presented and handlers could choose all that applied. Injury types were categorized as sprain (defined as ligament injury), strain (defined as muscle or tendon injury), fracture, laceration, contusion, abrasion, puncture, or other. Selections for cause of injury included collision with an obstacle, handler, or judge; environmental conditions such as wet grass; no known specific cause; or other. Agility course
obstacles listed included bar, spread, broad, panel, and tire jumps; dog walk; A-frame; seesaw; table; weave poles; and open and closed tunnels. For environmental conditions, an open-ended text field was available for respondents to provide additional information. Handlers could select multiple categories that contributed to the injury. A response of “other” to applicable questions also included an open-ended text field, which could be used if none of the provided response options were applicable.

If applicable, handlers could select multiple response options for the variables of anatomic site, type, and perceived cause of injury to describe a single injury incident. Additional questions regarding injured dogs included whether the specified injury was thought to have occurred during agility practice, competition, or in other settings; date of injury; amount of time required for recovery; whether medical intervention or other treatment was sought; and whether the same dog incurred multiple injuries.

**Statistical analysis**

For purposes of analysis, injuries were classified as mild or severe on the basis of the amount of time that respondents indicated was required for their dogs to recover. Injuries that resolved in < 1 month were classified as mild, and those that required ≥ 2 months for recovery were classified as severe. Injuries from which a dog had not fully recovered or for which recovery status was unclear were excluded from these categories and from analyses comparing variables on the basis of severity category.
Descriptive statistics for each variable were calculated and included a description of central tendency (mean), spread (SD and range), and distribution (frequency table and histogram). Associations of the handler-reported cause of injury with anatomic site and type of injury were examined by means of contingency tables and Pearson $\chi^2$ goodness-of-fit analyses. To avoid violating the assumption that each observation was independent, only the first-reported injury was included in these analyses. Additionally, an independent $\chi^2$ analysis was conducted for each anatomic site ($n = 18$) or injury type (12) across handler-reported cause of injury. The expected frequencies were taken to be equal across each handler-reported cause of injury. The $P$-values were adjusted using false discovery rate to account for multiple comparisons.

Pearson $\chi^2$ tests of independence were also used to examine whether associations existed between the severity of first-reported injuries (mild vs severe) and activity settings where these occurred (competition vs practice). The Yates correction for continuity was used where appropriate for these analyses.\textsuperscript{15} Statistical analyses were performed with statistical software.\textsuperscript{16,c} Values of $P < 0.05$ were accepted as significant.

RESULTS

Characteristics of handlers and dogs

Completed surveys were received from 1,669 handlers and included data for 3,801 dogs that participated in canine agility activities. Not all respondents answered every question. Characteristics of handlers were summarized (Table 1). The typical survey respondent (ie, handler) was female, $> 40$ years old, and
from North America. Most handlers (1,188/1,653 [71.9%]) had ≥ 5 years of experience in the sport, had practiced at least once weekly during the previous year (1,566/1,645 [95.2%]), and had entered canine agility competitions with their dogs at least once per month during this time (1,158/1,652 [70.1%]).

Dogs had a mean ± SD weight of 17.8 ± 9.1 kg (39.1 ± 20.1 lb; range, 1.8 to 75 kg [4.0 to 165 lb]) and height of 47.8 ± 11.9 cm (18.8 ± 4.7 in; range, 15.9 to 83.8 cm [6.25 to 33.0 in]). Dogs had participated in agility activities for a mean ± SD of 4.5 ± 2.7 years (range, 0.5 to 14.0 years). The 6 breeds most commonly represented were Border Collie (n = 639/3,801 [16.8%]), mixed (431 [11.3%]), Shetland Sheepdog (360 [9.5%]), Australian Shepherd Dog (252 [6.6%]), Labrador Retriever (133 [3.5%]), and Golden Retriever (131 [3.4%]). The population of dogs comprised 162 breeds in total.

Of 1,656 respondents that answered the question, 741 (44.7%) reported that in addition to agility activities, they and their dogs had participated in ≥ 1 other canine sport or activity. The most common of these were obedience (520/741 [70.2%]), rally-obedience (417 [56.3%]), conformation competition (219 [29.6%]), herding (217 [29.3%]), tracking (204 [27.5%]), and flyball (133 [17.9%]) activities.

**Injury characteristics**

In total, 1,209 of 3,801 (31.8%) dogs had an agility-related injury, and 334 of 1,209 (27.6%) dogs incurred > 1 injury. Mild injuries (809/1,602 [50.5%]) were more common than severe injuries (714 [44.6%]); the remainder (79 [4.9%]) were unclassifiable. Nine hundred and sixty nine of 1,602 (60.5%) injuries were
evaluated by a veterinarian, and no medical attention was sought for 270 (16.9%); 71 (4.4%) injuries were treated by means of orthopedic surgery. Other treatments sought for injuries included chiropractic care (691/1,602 [43.1%]), physiotherapy (412 [25.7%]), acupuncture (290 [18.1%]), and massage (97 [6.1%]).

Perceived causes were not identified for 430 of 1,602 (26.8%) reported injuries (classified as nonspecific injuries). Commonly reported causes of injury included direct contact with a bar jump (260/1,602 [16.2%]) and contact with or fall from an A-frame (235 [14.7%]) or dog walk (177 [11.0%]). In 318/1,602 (19.9%) reported injuries, handlers identified > 1 perceived cause for injury. Environmental factors were implicated in 202/1,602 (12.6%) injuries. These included slippery conditions on wet grass (n = 42), loose footing on dirt surfaces (17), hard dirt or dry grass surfaces (21), slippery indoor mat surfaces (15), slick wet contact surfaces on obstacles (15), uneven ground or debris on field (10), carpet or artificial turf surfaces (5) and glare from the sun (1). Further details were not provided for the remaining 76 environmental factors.

Distributions of injuries were summarized by anatomic site, severity, and type (Figures 1 and 2). Anatomic regions most commonly affected were the shoulder (349/1,523 [22.9%] injuries), back (282 [18.5%]), phalanges (forelimb or hind limb; 202 13.3%), and neck (189 12.4%). Injuries typically involved soft tissues (strain, 807/1,523 [53.0%]; sprain, 312 [20.5%]; or contusion, 200 [13.1%]). Seventy-nine of 1,602 injuries, involving 127 anatomic sites and 103
injury types were excluded from this analysis because they could not be classified as either mild or severe.

First-reported injuries attributed to the 3 most common perceived causes during the study (ie, those attributed to interactions with a bar jump, A-frame, or dog walk) were summarized by anatomic site and type (Figures 3 and 4). Several anatomic sites ($P < 0.05$ for shoulder, antebrachium and head; $P < 0.01$ for phalanges, stifle joint, carpal joint, and ribcage) and types of injury were significantly ($P < 0.05$ for strain; $P < 0.01$ for abrasion) associated with cause. Results of $c^2$ analyses and visual comparison of graphs revealed differences in the distribution of first-reported injuries attributed to each of the 3 most common causes, compared with the distribution when cause of injury was not taken into consideration (Figures 1 and 3).

Contact with a bar jump was the reported cause of a higher than expected number of shoulder (41), stifle joint (36) carpal joint (23), and antebrachium (22) injuries, whereas a higher than expected number of shoulder (48) and phalangeal (42) injuries were attributed to contact with or fall from an A-frame. Contact with or fall from a dog walk was associated with a higher than expected number of ribcage (14) and head (11) injuries, although neither of these injuries were frequently reported within the sample. Neck and back injuries were frequently reported but more equally distributed across all 3 perceived causes. Results of $c^2$ analyses and visual inspection of graphs indicated that contact with or fall from a dog walk was associated with a lower than expected number of strains (57) and a higher than expected number of abrasions (22), compared with
contact with or fall from an A-frame (87 and 10 injuries, respectively) or bar jump (98 and 3 injuries respectively). The distribution of all other injury types resulting from the 3 most common causes of injury was similar to that for all causes combined (Figures 2 and 4).

The proportion of injuries that occurred during agility competitions (739/1,602 [46.1%]) was similar to those that occurred during practice sessions (726 [45.3%]). The activity setting for 137 (8.6%) injuries was classified as unknown. Of 1,209 first-reported injuries, 497 (272 mild and 225 severe) and 518 (269 mild and 249 severe) occurred during competition and practice sessions, respectively. One hundred ninety-four injuries for which severity, setting, or both was unknown were excluded from this analysis.

The number of mild and severe first-reported injuries attributed to various obstacles was summarized for each setting; no significant associations were identified via $c^2$ analysis (Table 2). Injuries attributed to indirect or unknown causes ($n = 285$) and environmental conditions ($n = 146$) were also analyzed with no significant differences found. Six other perceived causes of injury reported by handlers had insufficient data points to obtain meaningful results from a $c^2$ analysis. These included human-dog collisions ($n = 15$), direct contact with or falls from the table (14), panel jump (6), long jump (7) and chute (closed tunnel; 21), and other mechanisms as reported by the handler (18). Because handlers could select multiple perceived causes for a given injury, the totals for all causes exceeded 1,209.
DISCUSSION

Results of the present study are consistent with the limited existing literature indicating that agility-related injuries affect approximately one-third of dogs participating in the sport and that soft tissue strains, sprains, and contusions to the shoulder, back, phalanges, and neck are most common types and sites of agility-related injury in dogs.⁶ In the present study, survey respondents indicated that 969 of 1,602 (60.5%) of the described injuries were evaluated by veterinarians.

In our study, 672 of 1,602 (41.9%) injuries were attributed to interaction with 3 specific pieces of equipment: bar jumps (260 [16.2%]), A-frames (235 [14.7%]), and dog walks (177 [11.0%]). Dogs typically perform many more jumps on a given agility course, compared with navigation of A-frames or dog walks. We examined a convenience sample of 36 international course maps from several regions (including Canada, the United States, and the European Union) from the 2011 competition year and found that, in general, for a course that included 20 obstacles, 13 of these were bar jumps, and only 1 A-frame and 1 dog walk were included; the remaining 5 obstacles comprised some combination of tunnels (open and closed), weave poles, other types of jumps (ie, broad, panel, spread, or tire jumps), and seesaws (unpublished data). Given the degree of exposure to bar jumps, it is not surprising that many injuries were attributed to contact with this type of obstacle. It is possible that injuries associated with a particular obstacle may in part be related to the previous obstacle as it may influence, for example, the speed and direction that the dog approaches the obstacle. Since the obstacles in a given competition are performed in specific
order, and the order changes among competitions, we were not able to evaluate the contribution of factors such as sequence of obstacles.

The fact that many injuries were attributed to interactions with A-frame or dog walk obstacles was disconcerting, considering the lower degree of exposure to these obstacles in typical competition courses. It is possible that the exposure to these obstacles could be different in practice sessions (eg, where handlers may choose to have a dog perform several repetitions of a particular obstacle in 1 training session). Levy et al\textsuperscript{6} reported that a slightly higher percentage of mild injuries (60\%) occurred in competition than in practice sessions, but found a nearly equal distribution of major or chronic injuries between competition and practice settings. In the present study, the distribution of mild and severe first-reported injuries incurred was similar between competition (n = 272 and 225, respectively) and practice settings (269 and 249, respectively).

Several sites and types of injury were significantly associated with the handler-reported cause of injury in dogs of the present study. An apparent difference in the distribution of injuries was found when considering the cause of injury, compared with the distribution when this was not taken into account. When all injuries were considered together, shoulders, backs, phalanges, and necks were ranked as the most common sites of injury. However, Pearson $\chi^2$ goodness-of-fit analyses and visual examination of data for the 3 most common causes of injury in this study indicated a higher than expected number of shoulders and phalanges were commonly injured when performing the A-frame task. In contrast, shoulder, antebrachium, stifle and carpal joint injuries were
more frequently reported than expected as resulting from contact with a bar jump, and contact with or fall from a dog walk was associated with a higher than expected number of ribcage and head injuries (although neither of these were frequently reported within the sample). Neck and back injuries were frequently reported but more equally distributed among the 3 most common causes of injury. Contact with or fall from a dog walk was associated with a high number of strains (although lower than expected) and a higher than expected number of abrasions, compared with the other 2 causes. The distribution of other injury types resulting from the 3 most common causes of injury was equally distributed across all causes, with strains, sprains, and contusions most frequently reported. These findings suggest that future research examining these obstacles should evaluate specific etiologies of injuries. Results of a recent study investigating kinetic variables in dogs landing from agility course jumps found high peak vertical force in the forelimbs (4.5 times body weight) when a bar jump was navigated at high speed (ie, 7.9 m/s). Those findings also indicated that further biomechanical studies are warranted to quantify relationships between anatomic sites and mechanisms of injury attributed to various agility activities. During the interval since the survey in the present study was conducted, some jurisdictions have implemented rules changes governing obstacle specifications. This may lead to changes in obstacle design and performance safety over time, which should be evaluated in future studies.

In the present study, 202 of 1,602 (12.6%) injuries were at least partially attributed to environmental factors. Commonly reported environmental factors
involved in injuries included slippery conditions on wet grass, loose footing on dirt surfaces, hard and slippery indoor mat surfaces, glare from the sun, and slick wet contact surfaces. Studies of horses participating in cross-country and steeplechase events have indicated that track conditions, speed, and distance of a race are important factors implicated in injuries. These factors should be considered when choosing suitable locations for agility practice and competitions, and further studies investigating these factors are warranted.

A considerable proportion of injuries (430/1,602 [26.8%]) reported in our study had an undefined (or nonspecific) cause of injury. When considered together with the 137 of 1,602 (8.6%) injuries that could not be attributed to a specific setting (agility practice vs competition), this suggests that handlers are not always attuned to identifying early signs of lameness or other injury in their dogs. This is not surprising, given that many clinicians regard diagnosis of canine lameness challenging.19–24

Limitations of the present study should be considered when evaluating the results. The accuracy of the study findings is restricted by participant recall, use of handler-reported data, and lack of confirmation of the reported injuries by veterinarians. Memory degradation and accuracy are concerns with any retrospective survey design. However, several studies in humans found high levels of agreement between retrospective self-reported data and prospectively collected objective data on sports injury variables, including number of injuries, anatomic location, type of injury, and level of treatment sought. Studies examining recall of parents for injuries and illnesses affecting their children
indicate that retrospective data for injuries resulting from accidents is more accurate than that for illnesses such as bronchitis or otitis, and that there is a greater likelihood of underreporting minor injuries than major injuries > 6 months after injury occurs. However, for incidents that are recalled, an acceptable level of agreement between parental reports and pediatrician records has been described. This suggests that findings of the present study could potentially underestimate the number of minor injuries that were incurred by agility dogs.

A prospective cohort or case-control study design would be preferential to a retrospective survey. However, results of our study indicate that nearly one-third (1,209/3,801) of the dogs included incurred ≥ 1 injury while practicing for or participating in agility competitions, and significant associations between the perceived cause of injury and anatomic site or type of injury were identified in this large group of dogs from various regions throughout the world.

Self-selection bias for survey respondents is also a recognized limitation of this study. Respondents that self-select or volunteer to participate in a study may not be representative of the population of interest. However, studies investigating differences between self-selected and random samples have shown that in situations where self-selected respondents are part of a community or care about the issue to be studied, their motivation to respond encourages them to provide more complete and higher quality data (eg, fewer missing data and more responses to open-ended questions), compared with that supplied by randomly selected participants. Comparisons of self-selected versus random samples often show few, if any, differences for many demographic
variables, including income, education, age, and gender.\textsuperscript{31–33} Although it was not possible to determine the effect of selection bias in the present study, it is likely that the respondents could be classified as belonging to a community (more specifically, an agility dog handler community) and that understanding the risks of injury to the dogs that they own or work with is an issue that they would care about.

Results of the present study provide a basis for experimental studies aimed at identifying mechanisms of various types of injury in dogs that participate in agility activities. An important future goal is to identify improvements in equipment, techniques, or both that may reduce the risk of injury among these canine athletes.

\begin{itemize}
\item[a.] Agility Association of Canada, North Gower, ON, Canada: Unpublished data, 2011.
\item[b.] Copies of the questionnaire are available from the corresponding author on request.
\end{itemize}
REFERENCES


Table 1. Selected characteristics of 1,669 agility dog handlers that participated in a 2009 survey to identify patterns of injuries (ie, type and severity of injury and affected region of the body) among dogs participating in agility training and competition events and examine associations between these patterns and perceived causes of injury.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. (%) of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>124 (7.5)</td>
</tr>
<tr>
<td>Female</td>
<td>1,530 (92.5)</td>
</tr>
<tr>
<td><strong>Age (y)</strong></td>
<td></td>
</tr>
<tr>
<td>≥ 19</td>
<td>45 (2.7)</td>
</tr>
<tr>
<td>20–29</td>
<td>164 (9.9)</td>
</tr>
<tr>
<td>30–39</td>
<td>318 (19.2)</td>
</tr>
<tr>
<td>40–49</td>
<td>449 (27.1)</td>
</tr>
<tr>
<td>50–59</td>
<td>490 (29.6)</td>
</tr>
<tr>
<td>≤ 60</td>
<td>191 (11.5)</td>
</tr>
<tr>
<td><strong>Canine agility experience (y)</strong></td>
<td></td>
</tr>
<tr>
<td>&lt; 5</td>
<td>465 (28.1)</td>
</tr>
<tr>
<td>5–10</td>
<td>807 (48.8)</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>381 (23.0)</td>
</tr>
<tr>
<td><strong>Trials entered in past year (No. of events/mo)</strong></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>109 (6.6)</td>
</tr>
<tr>
<td>&lt; 1</td>
<td>385 (23.3)</td>
</tr>
<tr>
<td>1</td>
<td>486 (29.4)</td>
</tr>
<tr>
<td>&gt; 1</td>
<td>672 (40.7)</td>
</tr>
<tr>
<td><strong>Frequency of canine agility practice in past year (No. of times/wk)</strong></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>7 (0.4)</td>
</tr>
<tr>
<td>&lt; 1</td>
<td>72 (4.4)</td>
</tr>
<tr>
<td>1</td>
<td>383 (23.3)</td>
</tr>
<tr>
<td>2–3</td>
<td>756 (46.0)</td>
</tr>
<tr>
<td>4–5</td>
<td>318 (19.3)</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>109 (6.6)</td>
</tr>
<tr>
<td><strong>Participation in other canine sports</strong></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>741 (44.7)</td>
</tr>
<tr>
<td>No</td>
<td>915 (55.3)</td>
</tr>
<tr>
<td><strong>Region</strong></td>
<td></td>
</tr>
<tr>
<td>North America</td>
<td>1,390* (84.3)</td>
</tr>
<tr>
<td>Canada</td>
<td>419 (25.4)</td>
</tr>
<tr>
<td>United States</td>
<td>966 (58.6)</td>
</tr>
<tr>
<td>Europe</td>
<td>207 (12.6)</td>
</tr>
<tr>
<td>Australia and New Zealand</td>
<td>28 (1.7)</td>
</tr>
<tr>
<td>South America</td>
<td>19 (1.2)</td>
</tr>
<tr>
<td>Africa</td>
<td>2 (0.1)</td>
</tr>
<tr>
<td>Asia</td>
<td>2 (0.1)</td>
</tr>
</tbody>
</table>

Percentages were based on the total number of responses for each category: sex (n = 1,654), age (1,657), agility experience (1,653), trials entered in the past year (1,652), frequency of agility practice (1,645), participation in other canine sports (1,656), and region (1,648). *Total includes 5 participants from Mexico and Bermuda.
Table 2. Results of Chi-square analysis for first-reported injuries incurred by dogs (n = 1,209) during agility competitions or practice sessions and number of injuries classified as mild or severe for each obstacle.

<table>
<thead>
<tr>
<th>Obstacle*</th>
<th>Competition</th>
<th>Practice</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar jump</td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Mild</td>
<td>46</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>37</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>A-frame</td>
<td></td>
<td></td>
<td>0.82</td>
</tr>
<tr>
<td>Mild</td>
<td>44</td>
<td>47</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>34</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Dog walk</td>
<td></td>
<td></td>
<td>0.91</td>
</tr>
<tr>
<td>Mild</td>
<td>26</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>22</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Seesaw</td>
<td></td>
<td></td>
<td>0.51</td>
</tr>
<tr>
<td>Mild</td>
<td>15</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Spread jump</td>
<td></td>
<td></td>
<td>0.89</td>
</tr>
<tr>
<td>Mild</td>
<td>10</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>12</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Tunnel</td>
<td></td>
<td></td>
<td>0.59</td>
</tr>
<tr>
<td>Mild</td>
<td>7</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Tire jump</td>
<td></td>
<td></td>
<td>0.09</td>
</tr>
<tr>
<td>Mild</td>
<td>32</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>13</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Weave Poles</td>
<td></td>
<td></td>
<td>0.93</td>
</tr>
<tr>
<td>Mild</td>
<td>16</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Severe</td>
<td>10</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

Data are reported as the number of first-reported injuries (total, 1,209); handlers were allowed to report up to 5 injuries/dog. Injuries that resolved in < 1 month were classified as mild, and those that required ≥ 2 months for recovery were classified as severe (on the basis of handlers’ responses). Not all injuries involved an obstacle; additionally, 194 injuries for which severity, setting, or both was unknown were excluded from this analysis. *Cause of injury was reported as resulting from direct contact with or falls from listed equipment.
FIGURE LEGENDS:

1. Common anatomic sites of mild (dark gray) and severe (light gray) injuries incurred by dogs during agility-related activities as reported by handlers in a 2009 internet-based international survey. Responses were received from 1,669 handlers regarding 3,801 dogs; 1,602 injuries were described for 1,209 dogs. A labeled diagram was provided to enable consistent reporting of affected body regions. Handlers could select multiple anatomic sites if applicable for each injury incident. Mild injuries were defined as those that resolved in < 1 month, and severe injuries required ≥ 2 months to resolve (according to the handlers' responses). Confirmation of reported injuries by a veterinarian was not required. Seventy-nine of 1,602 injuries involving 127 anatomic sites were excluded from analysis because recovery was not complete or recovery time was not clear. Regions classified as other included injuries to the tail.

2. Common types of mild and severe injuries incurred by the same dogs as in Figure 1. Sprains were defined as ligament injuries and strains were defined as muscle or tendon injury. Injuries classified as other were reported by handlers in their own words in open-ended text fields and included herniated disk (n = 24) arthritis (12), jammed toes (8) or joints (4), nerve injury (8), bone spur (4), dental injury (3), concussion (3), unspecified hernia (3) lumbosacral stenosis (2), joint capsule injury (2) and 1 each of unspecified brain injury, sesamoiditis, bee sting, cauda equina injury, cold or limber tail syndrome, fibrocartilaginous embolism, and spondylosis. Handlers could select multiple types of injury for a given injury incident. Seventy-nine of 1,602 injuries involving 103 types of injury were excluded from analysis because recovery was not complete or recovery time was not clear. See Figure 1 for remainder of key.

3. Common anatomic sites for first-reported injuries attributed to the 3 most common causes of agility-related injury (ie, those resulting from interactions with a bar jump [black bars], A-frame [light gray bars], or dog walk [white bars]) for the same dogs as in Figure 1. Results of Pearson χ² goodness-of-fit analyses indicated significant differences from expected equal injury distribution for several anatomic sites across the 3 most common causes of agility-related injury. *P < 0.05. † P < 0.01.

4. Common types of injuries attributed to the 3 most common causes of agility-related injury for the same dogs as in Figure 1. Results of Pearson χ² goodness-of-fit analyses indicated significant differences from expected equal injury distribution for injury type across the 3 most common causes of agility-related injury. *P < 0.05. †P < 0.01. See Figures 2 and 3 for key.
Figure 1.
Figure 2.
Figure 3.

No. of injuries

Anatomic site

- Shoulder
- Back
- Neck
- Thigh (upper)
- Phalanges (any)
- Stifle joint
- Loin
- Flank or croup
- Carpal joint
- Thigh (lower)
- Antebrachium
- Head
- Metacarpus or metatarsus
- Ribcage
- Footpads
- Other
- Unclear
Figure 4.
CHAPTER THREE

This chapter has previously been published in the Journal of the American Veterinary Medical Association. It has been reprinted with permission.

Survey-based analysis of risk factors for injury among dogs participating in agility training and competition events

Kimberley L. Cullen, MSc; James P. Dickey, PhD; Leah R. Bent, PhD; Jeffrey J. Thomason, PhD; Noël M. M. Moens, MSc, DVM, DACVS

From the Biophysics Interdepartmental Group (Cullen, Dickey), the Department of Human Health and Nutritional Sciences, College of Biological Sciences (Bent), and the Departments of Biomedical Sciences (Thomason) and Clinical Studies (Moens), Ontario Veterinary College, University of Guelph, Guelph, ON N1G 2W1, Canada; the Institute for Work and Health, 481 University Ave, Toronto, ON M5G 2E9, Canada (Cullen); and the School of Kinesiology, Faculty of Health Sciences, University of Western Ontario, London, ON N6A 5B9, Canada (Dickey).

This manuscript represents a portion of a dissertation submitted by Ms. Cullen to the University of Guelph Biophysics Interdepartmental Group as partial fulfillment of the requirements for a Doctor of Philosophy degree.

Supported by the Ontario Veterinary College Pet Trust Fund. Ms. Cullen was also supported by a Natural Sciences and Engineering Research Council of Canada Graduate Scholarship.

None of the authors have any conflicts of interest to disclose regarding this manuscript.

The authors thank Susan Garrett for helping to disseminate the electronic survey to participants, Dr. Sheilah Hogg-Johnson for statistical guidance and survey development, Dr. Jason Coe for survey development, and Jarrod Shugg for data entry.

Address correspondence to Ms. Cullen (kcullen@iwh.on.ca).
ABSTRACT

Objective: To identify potential risk factors for agility-related injuries among dogs.

Design: Internet-based, retrospective, cross-sectional survey.

Animals: 3,801 privately-owned dogs participating in agility training or trials.

Procedures: A retrospective electronic survey was used to investigate potential risk factors for injury among dogs participating in agility-related activities. Respondents were handlers recruited through member lists of large canine agility associations in Canada and the United Kingdom and through promotion via an agility blog site. Variables evaluated included demographic information for handlers and dogs, exposure variables (eg, frequency of agility practice and competition in the past year), and use of preventive measures intended to keep dogs fit for agility (warm-up, cool-down, or conditioning exercises; alternative therapeutic treatments [eg, acupuncture, massage, or chiropractic care]; or dietary supplement products).

Results: Data were collected from 1,669 handlers of 3,801 agility dogs internationally; 1,209 (32%) dogs incurred ≥ 1 injury. Previous injury (OR, 100.5), ≤ 4 years of agility experience for dogs (OR, 1.5), alternative therapeutic treatments (OR, 1.5), and Border Collie breed (OR, 1.7) were associated with increased odds of injury. Handlers with 5 to 10 or > 10 years of experience (OR, 0.8 and 0.6, respectively) and dogs with > 4 years of experience in the sport (OR, 0.6) were associated with decreased odds of injury.
Conclusions and Clinical Relevance: Specific factors were associated with agility-related injuries in dogs. Educational prevention strategies should target at-risk populations in an effort to reduce potential injuries. Future research should focus on the biomechanical factors associated with agility-related injuries. (J Am Vet Med Assoc 2013;242:1019–1024)

ABBREVIATIONS

CI Confidence interval

INTRODUCTION

Agility competition, one of the fastest growing canine sports worldwide,1 is a performance sport in which dogs and their handlers work as a team to navigate a sequence of obstacles. Dogs perform tasks that include jumping, weaving, making tight turns in tunnels, climbing ramps and seesaws, and moving on and off of, or across elevated surfaces while being timed for speed and scored for faults. The Agility Association of Canada² and the American Kennel Club² reported increases of approximately 10%/y in the number of participants involved in this sport from 2003 to 2010. With these increases in participation, there is also a growing interest in understanding the factors that influence the risk of injuries among dogs participating in the sport.

In a retrospective survey study³ to characterize agility-related injuries among dogs and examine associations between injury characteristics and perceived causes of injury, our group determined that 1209 of 3801 (32%) dogs incurred ≥ 1 injury during agility-related activities, with a total of 1602 injuries
reported. 969 (60.5%) of these 1602 injuries were examined by a veterinarian. The most common types of injury were sprains, strains, and contusions of the shoulder, back, phalanges, and neck. Levy et al\textsuperscript{4} found a similar pattern of injuries in another retrospective survey, and identified several potential risk factors for agility-related injuries, including a higher than expected proportion of injuries incurred by Border Collies, compared with dogs of other breeds.

Other studies\textsuperscript{3,4} regarding this subject have largely involved descriptive analytic methods and only examined factors in isolation. Multivariable techniques enable the investigation of individual risk factors while controlling for all others, and the use of these techniques enable a more comprehensive study of the complex interactions among the many variables that may contribute to agility-related injuries.\textsuperscript{5} The purpose of the study reported here was to conduct a large-scale retrospective survey to investigate potential risk factors for agility-related injuries among dogs. To our knowledge, the study reported here is the first to investigate potential risk factors for agility-related injuries by use of multivariable techniques.
MATERIALS AND METHODS

Sample

Survey participants were handlers of agility dogs who had Internet access and were willing and able to complete an electronic survey in English. Respondents from any geographic location were eligible to complete the survey.

Survey instrument and procedures

A retrospective cross-sectional survey was used to collect information on agility-related injuries among dogs. The survey instrument and research protocol were reviewed and approved by the University of Guelph Research Ethics Board.

Data were collected between March 16 and September 30, 2009. Participants were recruited for the survey through member lists of the Agility Association of Canada and United Kingdom Agility and through promotion on an internationally recognized canine agility dog handler's blog site. The survey was promoted on these parties' websites and Internet discussion lists and at local competitions.

Collection restrictions on the basis of internet protocol address were used to ensure that only 1 survey/respondent could be completed. Respondents with multiple dogs were instructed to complete a separate form for each dog. Additionally, for dogs that incurred multiple injuries, respondents were instructed to fill out separate injury forms for each injury (up to 5 injuries/dog).
The 27-item electronic survey was used to collect specific data on agility-related injuries incurred by dogs as recollected by handlers (confirmation of reported injuries by a veterinarian was not a requirement to participate in this study). A copy of this e-survey can be found in Appendix 1. Variables of interest for the present study included geographic location, other demographic information for handlers (eg, gender, age, and years of agility experience) and their dogs (eg, breed, age, height from the ground to the highest point of the shoulders [ie, withers], weight, number of years of participation in agility activities, use of preventive measures intended to keep dogs fit for agility (warm-up, cool-down, or conditioning exercises; alternative therapeutic treatments [eg, acupuncture, massage, or chiropractic care]; or dietary supplement products), and frequency of practice sessions and participation in agility events during the past year). Further details and other results of the survey are reported elsewhere.³

Data analysis

Data are presented as mean ± SD (for continuous variables) or number and percentage (for categorical variables). Variables were compared between dogs that incurred injuries and those that did not. Height and weight of dogs and the number of years of experience in agility competition (for the dog and the handler) were compared via independent Student t tests. Geographic region, breed, and variables for measures intended to keep dogs fit for agility activities (use of warm-up or cool-down exercises for agility events, conditioning exercises [including aerobic, strengthening, and proprioceptive or balance training],
alternative therapeutic treatments such as acupuncture, massage, and chiropractic care, and administration of dietary supplement products; all yes or no responses) were compared via Pearson $\chi^2$ analyses with values of $P < 0.05$ considered significant.

Unadjusted OR and 95% CI were calculated for all variables of interest by means of univariable logistic regression. Dogs that reported more than one injury in the survey were classified as having a previous agility-related injury. For several variables, categories were collapsed based on the distribution of responses. For geographic region, there were three primary regions where respondents competed: USA, Canada, and Europe. Respondents not competing in these regions were classified as Other. The breed variable was collapsed into 2 categories: Border Collie and Non-Border Collie based on the proportionally greater number of injuries incurred by this breed compared to all other breeds identified in the preliminary analyses.

The final multiple logistic regression model was built with purposeful selection of covariates.\textsuperscript{7,8} Variables that were significant at $P < 0.25$ in unadjusted analyses and remained significant in the multiple logistic regression model (adjusted OR) at $P < 0.15$ or removal of which from the final model resulted in > 20% change in the remaining variable estimates were chosen. Several interactions were tested, but none improved the overall fit of the model, and thus, none were included in the final multivariable model.

Box-Tidwell tests were used to determine whether the continuous variables in the model met the assumption of linearity.\textsuperscript{9} Significance and
goodness of fit of the final model were evaluated via the likelihood ratio test, Akaike information criterion, and Z statistic. Because there was a mean of < 5 observations (dogs/respondent), the hierarchic nature of the data was ignored in the multivariable model. All test assumptions were met, and statistical analyses were calculated with statistical software. In the final model, values of $P < 0.05$ were accepted as significant.

RESULTS

Completed surveys were received from 1,669 handlers from 27 countries including Canada, the United States, Europe, South America, Africa, Asia, Australia, and New Zealand and included data for 3,801 dogs; not all respondents answered every question. In total, 1,209 (31.8%) dogs had incurred an injury, and many of these (334 [28.0%]) had multiple injuries reported. Most dogs ($n = 2,592 [68\%]$) had not had an injury while participating in agility activities. Additional demographic information and characteristics of injuries incurred were reported elsewhere.

Injured dogs were significantly ($P = 0.02$) taller, had more years of agility experience ($P < 0.001$), and were more frequently described as having participated in warm-up ($P < 0.001$) and cool-down exercises for agility events ($P < 0.001$), compared with uninjured dogs (Table 1). The proportion of injured dogs that underwent alternative treatments (eg, acupuncture, massage, and chiropractic care) or were administered dietary supplement products was greater than that of uninjured dogs that received these treatments ($P < 0.001$ for both). There was no significant difference in weight between groups. Data on age at
injury was not evaluated because relevant information was not available for the uninjured dogs (2592/3801 [68.2%]).

Dogs in the study were of 162 different breeds; data for injured and uninjured dogs of the 10 breeds most highly represented in the survey were summarized (Table 1). The proportions of Border Collies and Standard Poodles injured (260/639 [41%] and 28/80 [35%], respectively) were greater than that of all breeds combined (1209/3801 [31.8%]); however, when tested via $\chi^2$ analyses, the difference was significant only for the Border Collie breed ($P < 0.001$). The proportion of Standard Poodles that incurred injury was not significantly different from that of all breeds combined, with ($P = 0.62$) or without ($P = 0.39$) Border Collies included in the sample. Given these findings, for our logistic regression models, we categorized injured dogs on the basis of breed as Border Collie or non–Border Collie (Table 2).

All of the variables of interest were significant predictors of injury in univariable logistic regression analyses, except for height ($P = 0.10$) and weight ($P = 0.44$). Height ($P = 0.606$) and weight ($P = 0.722$) met the assumption of linearity as evaluated via Box-Tidwell tests, but dogs’ years of experience in agility competition did not ($P < 0.001$). This variable was modeled with restricted cubic splines with 3 knots to account for nonlinearity. The unadjusted (univariable models) and adjusted (multivariable model) ORs for all variables of interest were summarized (Table 2).
The adjusted ORs from the final multiple regression model indicated that previous agility-related injury, ≤ 4 years of agility experience for dogs, use of alternative therapeutic treatments, and Border Collie breed were significantly associated with increased odds of injury. Dogs with > 4 years of agility experience and handlers having ≥ 5 years of experience were associated with decreased odds of injury in the final multiple regression model (Table 2).

After controlling for all other variables in the model, dogs with a previous agility-related injury were 100.5 times as likely to incur an injury, compared with dogs without such injuries. The relationship between dogs’ years of agility experience and the outcome (injury vs no injury) was nonlinear. Use of restricted cubic splines to model these factors and evaluation of plotted data (not shown) indicated that the odds of injury is increased for dogs with the fewest years experience in the sport (≤ 4 years, [OR, 1.5]). For dogs with between 4 - 10 years experience, the odds of injury is reduced (OR, 0.6).

The final adjusted model indicated a protective effect of increased handler experience. The odds of a dog incurring an injury were lower when its handler had 5 to 10 years (OR, 0.8) or > 10 years (OR, 0.6) of experience, compared with the odds for dogs that had handlers with < 5 years of experience in the sport.

Dogs in the United States had lower odds of injury than did dogs in Canada (reference category) in the univariable analysis. However, in the final model, there was no significant difference for dogs from any region (USA, Europe
or Other [which included South America, Africa, Asia, Australia, and New Zealand]) compared with dogs from Canada.

After controlling for all other variables in the model, the odds of injury for dogs that received alternative therapeutic treatments such as acupuncture, massage, and chiropractic care were higher (OR, 1.5) than those of dogs that did not. The use of warm-up and cool-down exercises, participation in some form of conditioning exercise (eg, aerobic, strengthening, or proprioceptive or balance training) and providing dogs with dietary supplement products were not significantly associated with injury in the final model, but their inclusion improved the fit of the final model and so these variables was retained.

Compared with competition in > 1 agility event/mo (the reference category), both participating in 1 event/mo and < 1 event/mo were associated with lower odds of injury in the univariable analyses; however neither of these variables remained significant in the final model. Although practicing > 1 time/wk was associated with higher odds of injury in the univariable analysis, this variable was also not significant when added to the final multivariable model.

After controlling for all other factors, the odds of injury were higher for Border Collies than for dogs of other breeds (OR, 1.7).

**DISCUSSION**

The primary purpose of the present study was to identify risk factors for agility-related injuries among dogs. The multivariable logistic regression analysis allowed us to consider the effect of each potential risk factor while controlling for
others. We identified several variables that are associated with increased odds of injury in the population of dogs studied. Previous agility-related injury, Border Collie breed, alternative therapeutic treatments such as acupuncture, massage, and chiropractic care, and fewer years of agility-related experience (< 5 years for handlers and ≤ 4 years for dogs) were significant risk factors for injury.

Studies\(^{13-20}\) in humans and horses have consistently shown that previous injury is strongly predictive of future injuries. This is supported by results of the present study, which revealed significantly greater odds of injury in dogs that had previous agility-related injuries (OR, 100.5), compared with dogs that did not have such injuries.

In our study, Border Collies had greater odds of injury than did dogs of all other breeds. This finding is consistent with the limited literature available.\(^4\) The Border Collie breed is more prevalent in the sport than other breeds; 639 of 3,801 (16.8%) dogs in our sample population were Border Collies. Dogs of this breed are known for their athletic stamina and willingness to perform tasks,\(^{21}\) and this may allow handlers to work with Border Collies for longer durations during competition and practice sessions than with other breeds. We included 3 exposure variables in our multivariable model: dogs' years of experience in agility competition, number of agility events/mo entered in the past year, and amount of practice per week. After controlling for these (and other predictor variables), Border Collies still had > 1.7 times the odds of injury, compared with other breeds. Another possible explanation is that the speed at which dogs navigate an agility course may potentially be related to the increased risk of injury. Border
Collies are known for drive, speed, and quickness in changing directions compared to other breeds.\textsuperscript{21} They were originally bred to herd stock, which requires great athletic prowess and stamina. Studies\textsuperscript{22–26} examining equine steeplechase, hurdle, and flat races have demonstrated that high rates of speed are associated with increased risk of injuries to the horses. Future research examining the biomechanical variables associated with agility-related activities may help to shed light on the observed differential risk for injuries among breeds.

The relationship between injury and the number of years of agility experience for dogs was nonlinear. Our results indicated that the odds of injury is increased for dogs with the least amount of experience in the sport (≤ 4 years, [OR, 1.5]). Interestingly, for dogs with > 4 years of experience, there is actually a decrease in the odds of sustaining injury (OR, 0.6). This measure could be an indication of skill acquisition. As Helton\textsuperscript{27} suggests in an examination of skill automaticity and expertise in agility dogs, with increased deliberate practice for agility events, dogs became more accurate and faster on course. These changes accompanying deliberate practice may include safer obstacle performance and better decision-making; thus, more experienced dogs may put themselves at lower risk for injury. This increase in expertise with experience may be related to the changes in odds of injury over time.

Dog experience may also be a proxy for age, which we could not include in our model. In the present study, two additional exposure measures: amount of practice per week and frequency of competitions per month were not significant in the multivariable analysis. This may be due to the imprecision of our survey
instrument for these variables. Future prospective epidemiological studies should include age to better examine the dynamics among age, experience, exposure, and injury in dogs that participate in agility-related activities. As increasing age has been shown to have a greater influence on injury over experience in sports for other species (eg, in equine jumping\textsuperscript{25,26} and various human sports).\textsuperscript{13,28}

An interesting relationship was found between handler experience and the odds of agility-related injury in dogs. In the unadjusted analysis, longer participation in the sport by handlers (5 to 10 or > 10 years, compared with < 5 years) was associated with an increased risk of injury in dogs. Intuitively, it would make sense that having a longer career in the sport would increase the likelihood that a handler would, at some point in time, have a dog incur an agility-related injury. However, when previous agility-related injury was entered into the multivariable model, the direction of effect reversed, and the odds of injury were significantly decreased for dogs handled by individuals with 5 to 10 years (OR, 0.8) or > 10 years (OR, 0.6) of experience in the sport. Inexperience has been documented as a risk factor for injury in many situations, including equestrian rider injuries,\textsuperscript{29} workplace injuries,\textsuperscript{30} and automobile accidents.\textsuperscript{31}

Use of alternative therapeutic treatments as preventative measures to keep dogs fit for agility were significantly associated with increased odds of injury (OR, 1.5). Additionally, while not significant in the final model, participation in conditioning activities including aerobic, strengthening, proprioceptive or balance training and the administration of dietary supplement products appeared to be associated with increased odds of injury. It may be that these actions were
implemented after an injury had already occurred in the dogs of this report or in the handler’s experience with other dogs. Handlers typically become more aware of the possibility for future injury after such an incident has occurred and may take a more proactive role in managing the health of dogs in their care on an ongoing basis from that point forward.

There was no relationship found between the use of warm-up and cool-down exercises and injury in our study. It is a commonly held belief among individuals in the canine agility community that these are important factors for reducing the risk of injury in dogs. In contrast, evidence from the literature on the effects of warm-up and cool-down exercises remains inconclusive. A recent systematic review of injuries in human athletes found equivocal results regarding whether these factors can modify the risk of injury.

Compared with dogs living in Canada, dogs in the United States had slightly lower odds of injury (although this was not significant in the final model). There was no significant difference observed for regions in Europe and the rest of the world when compared with Canada. There are differences in equipment standards or in styles of course design that exist among these regions. A more rigorous study design (eg, a prospective cohort or case-control study) would be necessary to investigate the relationship further.

The present study was not without limitations. Most notably, recall bias may have been a factor because data were collected retrospectively and reported by handlers and as such could not be easily verified. In addition, our
sampling strategy may have led to selection bias. Handlers had to be able to communicate in English and have access to the Internet to participate. Additionally, it is possible that handlers with a greater interest or personal experience with dogs injured in agility-related activities were more likely to complete the survey. Nevertheless, our sample included a large number dogs and handlers from various regions worldwide, and in fact, there were a greater number of uninjured dogs than injured dogs, making this issue less of a concern.

Previous studies of agility-related injury risk factors have been smaller in scale and have included simple descriptive analyses. We believe that the present study has several advantages over these studies. First, we obtained data for large numbers of uninjured and injured dogs and we were able to use multiple logistic regression analyses to estimate the effect of individual risk factors while controlling for other variables in the model. This led to different interpretations of the data than the simple univariate analyses alone would have, especially in regard to the protective effect that emerged for increased handler experience when the model was controlled for previous agility-related injury. We also were able to recruit participants from 27 countries worldwide, increasing the generalizability of our findings.

The results of the study reported here have important implications to guide future research and prevention activities aimed at reducing agility-related injuries in dogs. We recommend that agility organizations, instructors, judges and treating practitioners take measures to educate agility dog handlers about the risks for injury in the sport. This effort should target handlers that are new to the
sport or working with inexperienced dogs and those that work with Border Collies, given the higher odds of injury associated with these factors. We also believe that agility associations should consider implementing more comprehensive injury surveillance systems. The primary goal of such systems would be to collect injury and activity data from a representative sample of canine athletes in various geographic regions. Relevant data could then be shared with the research community and appropriate policy committees to provide a foundation for evidence-based decision making with regard to health and safety issues.

b. Copies of the questionnaire are available from the corresponding author on request.
REFERENCES


Table 1. Selected characteristics of dogs that did (n = 1,209) or did not (2,592) incur injuries during agility-related activities as reported by 1,669 agility dog handlers from 27 countries in a 2009 Internet-based survey.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Dogs</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uninjured</td>
<td>Injured</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>17.7 ± 9.3</td>
<td>17.9 ± 18.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>47.5 ± 11.9</td>
<td>48.3 ± 11.4</td>
</tr>
<tr>
<td>Canine agility experience (y)</td>
<td>4.2 ± 2.7</td>
<td>5.5 ± 2.5</td>
</tr>
<tr>
<td>Handler agility experience (y) (No. [%])</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 5</td>
<td>224 (30)</td>
<td>513 (70)</td>
</tr>
<tr>
<td>5 - 10</td>
<td>929 (43)</td>
<td>1238 (57)</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>607 (42)</td>
<td>827 (58)</td>
</tr>
<tr>
<td>Preventative care (No. [%])</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm-up exercise</td>
<td>2069 (82)</td>
<td>1167 (91)</td>
</tr>
<tr>
<td>Cool-down exercise</td>
<td>1396 (56)</td>
<td>899 (70)</td>
</tr>
<tr>
<td>Conditioning exercises*</td>
<td>1826 (73)</td>
<td>1062 (82)</td>
</tr>
<tr>
<td>Alternative therapeutic treatments †</td>
<td>1392 (55)</td>
<td>958 (74)</td>
</tr>
<tr>
<td>Dietary supplement products</td>
<td>1388 (55)</td>
<td>904 (70)</td>
</tr>
<tr>
<td>Breed (No. [% of breed])‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Border Collie</td>
<td>379 (59)</td>
<td>260 (41)</td>
</tr>
<tr>
<td>Mixed</td>
<td>305 (71)</td>
<td>126 (29)</td>
</tr>
<tr>
<td>Shetland Sheepdog</td>
<td>260 (72)</td>
<td>100 (28)</td>
</tr>
<tr>
<td>Australian Shepherd Dog</td>
<td>171 (68)</td>
<td>81 (32)</td>
</tr>
<tr>
<td>Labrador Retriever</td>
<td>99 (74)</td>
<td>34 (26)</td>
</tr>
<tr>
<td>Golden Retriever</td>
<td>106 (81)</td>
<td>25 (19)</td>
</tr>
<tr>
<td>Cocker Spaniel</td>
<td>63 (68)</td>
<td>29 (32)</td>
</tr>
<tr>
<td>Pembroke Welsh Corgi</td>
<td>56 (69)</td>
<td>25 (31)</td>
</tr>
<tr>
<td>Standard Poodle</td>
<td>52 (65)</td>
<td>28 (35)</td>
</tr>
<tr>
<td>Jack Russell Terrier</td>
<td>44 (73)</td>
<td>16 (27)</td>
</tr>
</tbody>
</table>

*Conditioning exercise included aerobic, strengthening, or proprioceptive or balance training. †Alternative therapeutic treatments included acupuncture, massage, and chiropractic care. ‡P value (Breed) for Border Collie and Standard Poodle compared with all other breeds combined. Only these breeds were analyzed separately as the proportions of Border Collies and Standard Poodles injured (260/639 [41%] and 28/80 [35%], respectively) were greater than that of all breeds combined (1209/3801 [31.8%]). * NA = Not analyzed separately.
Table 2. Unadjusted and adjusted ORs (95% CIs) of risk factors for injury among the same dogs as in Table 1 (n=3404, dogs with missing data were excluded from this analysis).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Injury (n = 940)</th>
<th>No Injury (n = 2,464)</th>
<th>Regression Models</th>
<th>Regression Models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Univariable Model</td>
<td>Multivariable Model</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unadjusted OR (CI)</td>
<td>Adjusted OR (CI)</td>
</tr>
<tr>
<td>Previous agility-related injury</td>
<td>316</td>
<td>0</td>
<td>132.3 (72.04–278.7)</td>
<td>100.5 (54.4–212.4)</td>
</tr>
<tr>
<td>Preventative care</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warm-up exercise</td>
<td>845</td>
<td>2,053</td>
<td>1.8 (1.4–2.3)</td>
<td>1.3 (0.9–1.7)</td>
</tr>
<tr>
<td>Cool-down exercise</td>
<td>630</td>
<td>1,379</td>
<td>1.6 (1.4–1.9)</td>
<td>1.0 (0.8–1.3)</td>
</tr>
<tr>
<td>Conditioning exercises*</td>
<td>762</td>
<td>1,811</td>
<td>1.5 (1.3–1.9)</td>
<td>1.1 (0.9–1.4)</td>
</tr>
<tr>
<td>Alternative therapeutic</td>
<td>671</td>
<td>1,366</td>
<td>2.0 (1.7–2.4)</td>
<td>1.5 (1.2–1.8)</td>
</tr>
<tr>
<td>treatments †</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dietary supplement products</td>
<td>638</td>
<td>1,385</td>
<td>1.6 (1.4–1.9)</td>
<td>1.2 (1.0–1.5)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>940</td>
<td>2,464</td>
<td>1.0 (1.0–1.03)</td>
<td>—</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>940</td>
<td>2,464</td>
<td>1.0 (1.0–1.01)</td>
<td>—</td>
</tr>
<tr>
<td>Region‡</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>269</td>
<td>600</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>United States</td>
<td>565</td>
<td>1,580</td>
<td>0.8 (0.7–0.9)</td>
<td>0.8 (0.7–0.9)</td>
</tr>
<tr>
<td>Europe</td>
<td>85</td>
<td>219</td>
<td>0.9 (0.7–1.2)</td>
<td>0.9 (0.6–1.2)</td>
</tr>
<tr>
<td>Other</td>
<td>21</td>
<td>65</td>
<td>0.7 (0.4–1.2)</td>
<td>0.7 (0.4–1.2)</td>
</tr>
<tr>
<td>Canine agility experience (y)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dogs**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–4</td>
<td>343</td>
<td>1122</td>
<td>1.6 (1.5–1.8)</td>
<td>1.5 (1.3–1.7)</td>
</tr>
<tr>
<td>&gt; 4–10</td>
<td>535</td>
<td>906</td>
<td>0.6 (0.5–0.7)</td>
<td>0.6 (0.5–0.8)</td>
</tr>
<tr>
<td>Handlers</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 5</td>
<td>133</td>
<td>485</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>5–10</td>
<td>506</td>
<td>1,200</td>
<td>1.5 (1.2–1.9)</td>
<td>0.8 (0.6–0.9)</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>301</td>
<td>779</td>
<td>1.4 (1.1–1.8)</td>
<td>0.6 (0.4–0.8)</td>
</tr>
<tr>
<td>Competitions entered in past</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>year (No. of events/mo)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 1</td>
<td>217</td>
<td>1,050</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>1</td>
<td>271</td>
<td>740</td>
<td>0.9 (0.7–1.02)</td>
<td>0.9 (0.8–1.2)</td>
</tr>
<tr>
<td>&lt; 1</td>
<td>217</td>
<td>674</td>
<td>0.7 (0.6–0.9)</td>
<td>0.9 (0.7–1.1)</td>
</tr>
<tr>
<td>Frequency of agility practice</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in past year (No. of times/wk)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>£ 1</td>
<td>217</td>
<td>681</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>&gt; 1</td>
<td>723</td>
<td>1,783</td>
<td>1.3 (1.1–1.52)</td>
<td>1.1 (0.9–1.4)</td>
</tr>
<tr>
<td>Breed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All other breeds</td>
<td>727</td>
<td>2,137</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>Border Collie</td>
<td>213</td>
<td>327</td>
<td>1.9 (1.6–2.3)</td>
<td>1.7 (1.4–2.2)</td>
</tr>
</tbody>
</table>

Data are shown for 3,404 of 3,801 dogs; those with missing data were excluded from analysis.* P values presented in this column are for the final multivariable logistic regression model. In the univariable models, all variables were significant except for height (P = 0.10) and weight (P = 0.44). ** Data from canine agility experience for dogs (y) was modeled with restricted cubic splines with 3 knots to account for nonlinearity. † Data from handlers living in South America, Africa, Asia, Australia, and New Zealand were classified as other in this analysis. — = Not applicable (variable was removed from the final model).
CHAPTER FOUR

This chapter has been prepared for publication.

Feasibility of collecting fine-wire electromyographic recordings in four canine shoulder muscles during highly dynamic tasks

Kimberley L. Cullen, MSc; James P. Dickey, PhD; Stephen H. M. Brown, PhD; Stephanie G. Nykamp, DVM, DACVR, Leah R. Bent, PhD; Jeffrey J. Thomason, PhD; Noël M. M. Moens, MSc, DVM, DACVS

From the Biophysics Interdepartmental Group (Cullen, Dickey, Brown), the Department of Human Health and Nutritional Sciences, College of Biological Sciences (Brown, Bent), and the Departments of Biomedical Sciences (Thomason) and Clinical Studies (Nykamp, Moens), Ontario Veterinary College, University of Guelph, Guelph, ON N1G 2W1, Canada; the Institute for Work and Health, 481 University Ave, Toronto, ON M5G 2E9, Canada (Cullen); and the School of Kinesiology, Faculty of Health Sciences, University of Western Ontario, London, ON N6A 5B9, Canada (Dickey).

This manuscript represents a portion of a dissertation submitted by Ms. Cullen to the University of Guelph Biophysics Interdepartmental Group as partial fulfillment of the requirements for a Doctor of Philosophy degree.

Ms. Cullen was supported by a Natural Sciences and Engineering Research Council of Canada Graduate Scholarship.

None of the authors have any conflicts of interest to disclose regarding this manuscript.

The authors thank Ryan Frayne and Robert Caryn for their help with data collection and building the A-frame testing obstacle. We would also like to thank Leila Kelleher for her help with data collection and Peter Wegscheider for his help with building the A-frame obstacle. We also owe our thanks to Deryl Drysdale for donating two agility jumps for our testing protocol, to Sarah Hughes of Details Dog Training for donating the materials for the A-frame obstacle and to Darlene Woz of Rubber on the Run and Rochelle Hall Bagwell of American Recycling for supplying the materials and labour to make the rubber skin coating for the A-frame.

Address correspondence to Ms. Cullen (kcullen@iwh.on.ca).
ABSTRACT
This study investigated the feasibility of obtaining ultrasound-guided intramuscular fine-wire electromyographic (fEMG) recordings from four canine shoulder muscles during highly dynamic activities. Four cadaveric canines were utilized to confirm the appropriate anatomical landmarks and the use of real time ultrasound guidance for electrode placement for four shoulder muscles: Biceps Brachii (BB), Supraspinatus (SP), Infraspinatus (IF), and Triceps Brachii – Long Head (TBLH). Electromyographic activity of the left BB, SP, IF, and TBLH was then recorded in two research dogs while walking and trotting to refine the data collection procedures. Finally, the full experimental protocol was piloted with two client-owned, specially-trained agility dogs, confirming the feasibility of collecting fEMG recordings while performing dynamic, highly-specific agility-related tasks and verifying our EMG amplitude normalization protocol to enable comparisons across muscles and performance tasks. We present specific guidelines regarding the placement of fEMG electrodes and data collection/normalization procedures to enable investigations of muscle activation during dynamic activities.

ABBREVIATIONS
fEMG = fine-wire electromyography
BB = Biceps Brachii
SP = Supraspinatus
IF = Infraspinatus
TBLH = Triceps Brachii – Long Head
CT = Computed Tomography
INTRODUCTION

In recent years, the sport of canine agility has been gaining in popularity throughout the companion dog population.\textsuperscript{1,2} Data collected by the American Kennel Club, one of the largest agility organizations in North America, indicates a 10% annual growth rate over the last two decades, while setting new records in 2012 for the number of entries to agility events at over 1.1 million dogs.\textsuperscript{2}

Soft tissue injuries such as strains, sprains and contusions are relatively common in agility; approximately 32% of dog athletes have developed an injury while competing or training in agility.\textsuperscript{3,4} The shoulder and certain activities, such as jumping and climbing the A-frame obstacle, have been identified in two recent retrospective surveys, as the most common body part and obstacles associated with injury.\textsuperscript{3,4}

With these increasing participation rates, and the knowledge that nearly a third of agility dogs are injured in this sport, there is a growing interest in understanding the pathophysiology of shoulder lameness among these canine athletes. Canine shoulder injuries present as particularly difficult clinical challenges. The soft tissues covering the joint make palpation difficult and the degrees of freedom of movement across the joint complicate diagnosis.\textsuperscript{5} Although case reports of injuries and surgical techniques for repairs are
frequently reported,\textsuperscript{5–7} few biomechanical studies describe the normal muscular activation features of canine gait for these shoulder muscles.\textsuperscript{8–11}

Biomechanical tools such as force plates, electromyography and motion-capture systems have been applied to study canines as models of human disease such as osteoarthritis,\textsuperscript{12–14} and in canine companion animals.\textsuperscript{15} Normal muscle function in healthy canines has been examined at a walk,\textsuperscript{8,16,17} at a trot,\textsuperscript{9,18–21} and at a gallop.\textsuperscript{10} Several biomechanical studies have examined clinical canine populations including: partial and pancarpal arthrodesis,\textsuperscript{22} osteoarthritis,\textsuperscript{23–25} cranial cruciate ligament rupture\textsuperscript{26} and hip dysplasia.\textsuperscript{27,28} However, limited research has evaluated the biomechanics of canine sport and agility.\textsuperscript{29–31}

To further our understanding of how the shoulder muscles function when performing these high-risk agility obstacles, we would like to measure muscle activation in four shoulder muscles continuously while dogs perform agility-specific tasks (i.e., jumping and climbing the A-frame). The four shoulder muscles of interest in this study were chosen both for their recognized importance in canine locomotion\textsuperscript{8–11} and for their frequency of observation in injured canine athlete populations.\textsuperscript{5–7}

The use of intramuscular fine-wire electrodes was preferred to the use of surface electrodes; they provide selective measures of muscle activity while avoiding skin movement artifact and minimizing crosstalk from adjacent muscles, which are known limitations of surface electrodes.\textsuperscript{32,33} While evidence to support
the use of intramuscular fine-wire electromyography (fEMG) techniques in
dynamic activities such as agility-related tasks is limited;\textsuperscript{34–37} recent studies
comparing the fEMG recordings to those collected using surface EMG electrodes
have demonstrated a high level of agreement and repeatability in human
cycling\textsuperscript{34} and running\textsuperscript{35} tasks.

The use of intramuscular EMG techniques are well-established and have
been used in neurophysiological and biomechanical studies in humans since the
early 1960s\textsuperscript{38–40} and in dogs for the past 30 years.\textsuperscript{11,19,20,41–43} However, with a
few notable exceptions,\textsuperscript{8–10} most studies in dogs have used highly invasive patch
electrodes that are sewn directly on the muscle surface;\textsuperscript{11,19,20,42,43} the feasibility
of inserting these electrodes using a non-surgical technique has not been
reported in a canine population to date. The use of an ultrasound-guided,
minimally invasive fEMG technique, which has been validated in humans,\textsuperscript{34,39,40}
would be preferred to a surgical insertion technique, given our population of
interest is client-owned, highly trained agility dogs.

The purpose of this study was to investigate the feasibility of using an
ultrasound-guided insertion technique to obtain reproducible insertion of the fine-
wire electrodes (and appropriate system grounding and harnessing) to enable
fEMG recordings to measure the muscular activation in four shoulder muscles:
Biceps Brachii (BB), Triceps Brachii – Long Head (TBLH), Supraspinatus (SP),
and Infraspinatus (IF) continuously during highly dynamic, agility-specific tasks.
METHODS

Participants

Two participant groups were used to investigate the feasibility of using ultrasound-guided fEMG recordings to collect canine muscle activation patterns in four shoulder muscles.

**Group 1:** The first group was a convenience sample of four cadavers (2 Beagles, 1 mixed breed and 1 Pit Bull Terrier; with a mean ± SD: weight of 14.8 ± 7.4 kg and height of 41.3 ± 7.4 cm) from the University of Guelph Central Animal Facility (CAF) autopsy suite with clinically normal and undisturbed pectoral limb muscles. The exact duration of time between euthanasia and radiographic examination was unknown, however, the mild gas accumulation in the tissues did not impede the ultrasound imaging or CT scans. This group was chosen to establish and validate the fEMG insertion techniques.

**Group 2:** The second group included a convenience sample of two research dogs (Beagles; mean ± SD: weight of 10.9 ± 5.2 kg and height of 35.6 ± 1.8 cm) from the CAF colony and two client-owned agility dogs (Border Collies; mean ± SD: weight of 14.6 ± 2.5 kg and height of 48.9 ± 1.8 cm) to evaluate the fEMG procedures, focusing particularly on the use of the harness assembly designed for this experiment, evaluating the quality of the signal from the fEMG channels and evaluating whether we could obtain consistent fEMG measurements throughout the experimental session. The research dogs were not trained in agility and were tested first while walking, trotting and running over
level ground surfaces. The trained agility dogs participated in the full experimental protocol as indicated below. All dogs were evaluated using two independent orthopedic examinations (limb palpation and gait analysis at a walk and trot). These examinations were performed by a board certified veterinary surgeon with experience in kinetic and kinematic gait analysis to assure that the dogs were clinically normal.

Method of recruitment and consent

We followed university protocol for obtaining research animals for phases 1 & 2 of the study. For Phase 3, two healthy client-owned agility dogs were recruited from the local agility community. The handlers provided their written informed consent. All procedures were approved by the University of Guelph’s Animal Care Services Animal Utilization Policies.

Electromyography

Electrode preparation

The thin and flexible intramuscular fEMG electrodes (two wires, each 100µm diameter stainless steel 316 insulated with Formvar; California Fine Wire, Grover Beach, CA, USA) were prepared by forming a loop of wire and threading the ends down the bore of a 1.5” (SP, IF, TBLH) or 2” (BB), 27.5 gauge hypodermic needle and then cutting the tip of the loop. A small section (~ 5 mm) of Formvar insulation from the tip of each electrode wire was removed and the tips were offset with respect to each other and then bent around the edge of the needle to form a barb. These assemblies were sterilized by steam autoclave.
Skin Preparation

The location of the BB, SP, IF, TBLH muscle bellies were located by manual palpation. The hair overlying the muscle bellies was trimmed with a clipper in small patches (2cm by 2cm) in Phases 1 & 2. In Phase 3, clipping was only performed on the area where a 2.5 cm, circular, silver/silver chloride grounding surface electrode (pre-gelled, Ag-Ag/Cl, 10mm inner diameter, MediTrace 130, Kendall, MA, USA) was placed (on the skin over the left inner thigh). In phases 2 & 3, the skin was anaesthetized using Emla cream (at 1.5g/10cm², Astra-Zeneca, Sweden) to eliminate discomfort as the needle penetrated the skin; no discomfort persisted following removal of the needle. Isopropyl alcohol was used to prepare the skin and as a medium to transmit the ultrasound.

Ultrasonographic Examination

We performed B-mode, real-time ultrasonography over the shoulder muscles of interest (8 MHz micro-convex transducer, GE Healthcare Logiq P5 Ultrasound System). All needle insertions were performed by a board certified veterinary radiologist with expertise in musculoskeletal ultrasonography.

Electrode Insertion

All electrodes were placed into the muscles of interest on the left side of the dog. Electrodes were positioned relative to adjacent anatomical landmarks (see Table 1). The harness was secured to the dog before fEMG insertions. Neck and chest straps were adjusted to allow for adequate range of motion while
preventing the harness from slipping due to motion. Dogs were then placed lying down on their right sides with the left shoulder in neutral position. Each needle/EMG electrode was limited to one use. The fine-wire electrodes were inserted using the hypodermic needle, which was retracted immediately following insertion (see Figure 1). A surface electrode was used to ground the system and was placed on the left inner thigh. The wires were connected to the amplifier modules (Trigno Wireless Sensors, Delsys, Boston MA, USA), leaving a loop of excess wire as strain relief, and were secured via a harness to the dog (See Figure 2).

**Kinematic Parameters**

*Video Camera*

Temporal data were collected using a 30 Hz digital video camera (Canon Vixia HFM31) for the third phase of pilot testing only (see details below).

*Accelerometer*

Dogs in Phase 2 & 3 wore an accelerometer (Trigno Wireless Sensor, Delsys, Boston MA, USA) secured to the left lateral forelimb just distal to the elbow joint using Vet Wrap.

*Harness*

A Ruffwear Web Master™ Harness (size Small, Ruffwear, Oregon USA) was modified to meet the requirements for securing the wireless fEMG transducers to the dog without interfering with electrode placement (See Figure 2). The ribcage strapping was removed and repositioned as a neck strap and the
length of material covering the shoulder regions was trimmed back to prevent interference with the electrode insertion sites. Elastic strapping was sewn onto the top of the harness to hold the transducers and based on Phase 2 testing, four separate hook and loop closure Velcro straps were attached to the harness to help keep the wires from becoming tangled together and to provide strain relief for the wires between the insertion sites and the wireless transducers.

**Procedures**

*Phase 1: Establishing fEMG insertion protocol.*

Cadavers were placed on their right sides to approximate the relaxed positioning of the live animals. The protocol was initially performed on two dogs, in which the leg fur was clipped in 2 cm by 2 cm locations overlying the left BB, SP, IF, TBLH muscle bellies. The protocol was also performed on two of the dogs without shaving the fur over the target muscle sites. Skin was prepared with isopropyl alcohol, which facilitated acoustic coupling for the ultrasound examination. Target muscles were imaged continuously using ultrasound by a veterinary radiologist, while pairs of fine-wire electrodes were introduced into BB, SP, IF, and TBLH via sterilized small-gauge, hypodermic needles. The needles were then retracted. The exact location of the electrodes was confirmed by dissection (all dogs) and through CT scanning (for the 3rd and 4th dogs only; see **Figure 3**). The final anatomical landmarks for identifying needle insertion points and the direction and depth of insertion was modified based on the learning from the initial animals. The cadavers were returned to the autopsy suite and were disposed of in accordance with university protocol for animal utilization policies.
Phase 2: Establishing fEMG data collection protocol with research dogs.

Research dogs from the Central Animal Facility (CAF) colony were led to the Comparative Clinical Research Facility by an OVC handler. The animals were given two independent orthopedic examinations and then topical anaesthetic cream was applied to the insertion sites. While waiting for the anaesthetic cream to take effect (i.e., 10 minutes), the animals were fitted with a harness on which the wireless amplifier modules were held. The animals were then lifted onto the table using a 2-person lift technique, and were laid resting on their right side facing the Veterinary Radiologist. The skin was prepared with isopropyl alcohol. Target muscles were imaged continuously using Ultrasound, while pairs of fine-wire electrodes were introduced into BB, SP, IF, and TBLH via sterilized small-gauge, hypodermic needles using the anatomical landmarks, direction and depth of needle insertion identified in Phase 1 (see Table 1). The needles were then retracted. The wires were then secured to the amplifier modules with standard spring-type connectors, which were attached to the harness. The ground surface electrode was attached to the left inner thigh. An additional Trigno sensor, which was used as an accelerometer was also secured to the left lateral forelimb just distal to the elbow joint using Vet Wrap. These dogs were not trained in agility, so our focus was limited to walking and trotting on level ground. Data were recorded during locomotion of the dogs using the following protocol: Trials 1-3 were recorded at a walk and trials 4-6 were recorded at a trot. After data collection, the wires were removed by gentle continuous traction and then examined for evidence of breakage. The
transmitters and the harness were then removed and the animals were returned to the CAF by the OVC handler.

Based on findings in Phase 1, we also evaluated the necessity of clipping the fur to achieve adequate signal properties by performing the protocol on one of the dogs without clipping the fur over the target muscle sites and the ground electrode site.

Phase 3: Establishing fEMG data collection protocol with client-owned dogs.

We used two client-owned dogs for the third phase of the study in which we extended our approach and focused on collecting additional fEMG recordings while the dogs performed agility-specific tasks (i.e., jumping and ascending/descending an A-frame). Data were recorded during locomotion of the dogs using the following protocol: 1) Baseline measures: three successful trials were recorded at a walk while the dog covered a back-and-forth pattern of a 6 m (20’) distance. 2) Ascending/Descending the A-frame (2 height conditions): six trials were recorded with the dog running up the A-frame with the apex set at 1.67 m (66”) and 1.75 m (69”). At both heights, three trials were performed with the camera on the ascending side of the A-frame and three were performed with the camera on the descending side. The presentation order for performance height was alternated for each participant, although the ascending task always preceded the descending task. The dog was left a minimum distance of 4.5 m (15’) from the A-frame and began the task by running towards the A-frame when initiated by the handler. After running up the A-frame, the dogs continued over
the apex (as per usual agility performance of this obstacle) and exited the A-frame out of the cameras’ field of view. Dogs could continue off the A-frame a minimum of 4.5 m (15’) at the end of this task. 3) Jumping task: three successful trials were recorded with the dog performing two consecutive bar jumps spaced 4.5 m (15’) apart set at 55cm (22”) from the ground. The dog started a minimum distance of 4.5 m (15’) from the first jump and began the task when released by the handler. 5) Repeat of baseline measures: three successful trials were recorded with the dog repeating the walking task.

Data Analysis

EMG Signal Collection and Processing

The EMG and accelerometer signals were wirelessly transmitted to the receiver (Delsys, Boston MA, USA), amplified by a factor of 909, with a full dynamic range of +/- 5V, sampled at 2000 Hz, digitized with a 16 bit A-D converter, visually displayed for quality assurance and stored for off-line analysis. The EMG signals were band-pass filtered between 100-500 Hz with a 2nd order Butterworth filter, rectified and low-pass filtered at 3 Hz with a 2nd order Butterworth filter to remove low frequency movement artifact and high frequency noise in accordance with established procedures and ISEK guidelines.

All EMG samples were screened by visual inspection and assessed for quality of recording using a custom-written LabVIEW (National Instruments, Austin TX, USA) program. Recordings that contained high levels of artifact, which
could not be removed with signal filters, were also excluded from analyses as these samples may have led to a false interpretation of muscle activation (111 of 3645 stride events were excluded in this way).

*Identifying individual strides*

We intended to use the accelerometer recordings to identify the timing in the EMG signal that corresponded to “paw down” or the initiation of left forelimb support for each stride until the next consecutive “paw down” event for this limb, based on the step detection algorithms presented by Ying et al.46 This appeared feasible on the two preliminary research dogs; however, cursory examination of the data collected for the first agility dog showed that the more dynamic agility activities resulted in saturation of the acceleration signal and therefore this analysis was not possible. Thus, we introduced an alternate approach for the testing of the second agility dog. The video records were synchronized with the EMG data using a pulse that was recorded together with the EMG and turned on a light in the video frame. The timing of the "paw down" stride events in the video records was used to identify the individual strides the fEMG signals. These individual trials were rubber-banded to 100 percent of stride and ensemble averaged.

*EMG Normalization*

Given our sample of interest, it was impractical to acquire muscle activations from a reference maximal voluntary contraction. Submaximal dynamic tasks have been used successfully for normalization to allow direct comparisons
between subjects and within-subjects across tasks and testing dates.\textsuperscript{47–51} The use of the ensemble-averaged PEAK amplitude for normalization has been shown to minimize inter-subject variability in human gait analysis.\textsuperscript{52,53} The average PEAK amplitude recorded during the walking task was planned for use as a reference activity for EMG normalization in order to compare activation patterns across muscles and different agility-specific tasks.

In this pilot testing stage, we examined the ensemble-averaged walking EMG data to compare the similarity of recordings from those recorded at the beginning of the testing session (i.e., pre-agility tasks) to those recorded at the end of the session (i.e., post-agility tasks). We were specifically interested in whether the dynamic agility tasks would cause the electrodes to migrate or pull out, and whether these tasks would introduce motion artifact to the EMG signals.

RESULTS AND DISCUSSION
Phase 1: Establishing fEMG insertion protocol.

Using four cadavers, we established our fEMG insertion protocol. Clipping/shaving fur at the insertion site was not required to obtain clear ultrasound imaging of the musculoskeletal structures to enable placement of the electrodes.

Using both dissection and CT imaging (see Figure 3), we confirmed placement of the fEMG electrodes pairs into the four shoulder muscles of interest. A 1.5” 27.5 gauge hypodermic needle was used for the insertion of the TBLH, SP and IF electrode pairs into the muscle bellies. Our initial attempts to insert the BB fEMG electrodes using a 1.5” needle were unsuccessful. Due to the longer
distance to reach the BB muscle belly from the insertion point, the length of the needle was too short to ensure the electrodes were placed into the middle of the muscle belly. Dissection and CT Imaging confirmed that with the use of the shorter needle, the wires did not enter the BB muscle belly. Changing to a 2” long needle was sufficient to ensure the BB wires reached their target location and remained in place. The final anatomical landmarks, needle insertion points, distance and depth of electrode insertions used in this protocol are presented in Table 1.

**Phase 2: Establishing fEMG data collection protocol with research dogs.**

Using two research dogs, we confirmed the order of electrode insertions, the final configuration of the harness to secure the electrodes to the wireless transducers, and the ability to capture fEMG recordings for all four muscles of interest while the dogs moved at a walk and trot over a short distance on level ground.

It was determined that clipping/shaving fur at the muscle insertion sites was not required to allow for acceptable signal quality. Thus, trimming the fur was not performed in Phase 3 for the shoulder muscle insertion sites. However, it was confirmed during this phase of testing that clipping the fur was necessary in order to secure an adequate skin contact for the surface electrode that grounded the system. Clipping the fur at the ground electrode site was added to the final experimental protocol for Phase 3 testing. Due to the barbs on the wires, we determined that it was not possible to redirect the needle following initial insertion so careful planning and good patient compliance are essential.
To prevent the electrode wires from becoming tangled, and to avoid having them become dislodged during the testing phase, we inserted electrodes in the following order: SP, IF, TBLH, and BB. Inserting the BB wires last in the sequence was done strategically, as we discovered that they could be easily dislodged during the insertion of the other muscle sites if they were placed earlier in the order. This occurred primarily because a longer wire was required in order to reach from the BB muscle belly to the amplifier module secured in the harness. We also attached four hook-and-loop closure Velcro straps to the harness to prevent the wires from becoming tangled together and to provide strain relief for the wires between the insertion sites and the wireless amplifier modules. As each new pair of wires were inserted, they were laid onto the labeled Velcro hook fabric attached to the Harness for that muscle, secured to the spring connectors on the harness and then the loop fabric Velcro strap was secured over the hook fabric to help keep the wires in place and minimize tangling among the pairs of wires from other muscle sites.

The raw fEMG signals were wirelessly transmitted to the receiver and were visually inspected for quality. Signals were captured for all four muscles while the research dogs were led through the lab space at a walk, trot and run on level ground.

**Phase 3: Establishing fEMG data collection protocol with agility dogs.**

Using two client-owned highly trained agility dogs, we pilot-tested the full experimental protocol to investigate shoulder muscle activation while performing dynamic agility tasks. When securing the harness and electrodes to the dogs, we
discovered that the border collies were smaller in chest girth compared to the research dogs tested in Phase 2. As a result, adjustments were made to the harness to account for smaller overall girth circumference and additional material was removed from the harness over the left shoulder area to ensure adequate access to the fEMG insertion sites for the BB, SP and IF muscles. The needle sizes identified as appropriate in the previous phases using the research dogs were still appropriate with these client-owned dogs.

The raw fEMG signals were wirelessly transmitted to the receiver and were visually inspected for quality. Signals were captured from all four muscles while the agility dogs performed the walking and agility-specific tasks.

The data were imported into a custom written LabVIEW program for further analysis. Attempts were made to use the recorded accelerometer data to identify stride events for the first agility dog. However, the signals from the accelerometer saturated and it was not possible to use the step detection algorithms identified by Ying et al.\textsuperscript{46} for this purpose. Instead, a common synchronization signal on a secondary channel was introduced to the testing protocol for the second agility dog to provide a temporal link across the EMG and video recording devices for data analysis.

Using this procedure, the fEMG recordings for the pre- and post-walking strides were extracted and compared for Dog 2 (see Figure 4). Overall, the characteristic features of the walking strides remained consistent for all four
muscles between the pre- and post-agility testing sessions, suggesting that the highly dynamic agility tasks did not cause the wire electrodes to migrate.

As shown in Figure 4, the PEAK amplitude recorded for walking was higher for the TBLH and SP muscles and lower for the BB and IF muscles. An observation made by the research team during these testing sessions was that the agility dogs tended to be more excited at the start of the experiment, likely because they could see the A-frame and jump equipment and could anticipate that they would be given permission shortly to perform these obstacles. The dogs demonstrated a much calmer, relaxed walking style during the post-testing walking session compared to the pre-testing session. This may explain the higher peak amplitudes observed for the TBLH and SP muscles.

Both of the BB and IF electrode pairs were replaced at the end of the pre-agility task walking trials. Real-time visual inspection of the fEMG recordings for these muscles indicated a signal detection error and these wire pairs were replaced prior to the initiation of the agility-specific tasks. Although the same land-marking and electrode insertion procedures were used, the replaced electrodes would have been in a slightly different location. This may help explain why for both of these muscles, the post-testing walking trials exhibited similar characteristic features but higher PEAK activity.

For both agility dogs during this pilot testing phase, once the electrodes were successfully inserted into the muscle bellies and were visually observed to be recording with acceptable signal quality during the pre-testing walking tasks,
all electrodes remained in position with acceptable signal quality for the remainder of the testing sessions. That is, none of the electrodes were dislodged as a result of the highly dynamic nature of the agility tasks. For this reason, and the observation that the dogs exhibited more natural walking patterns in the post-test walking trials, we resolved to use the average PEAK amplitudes recorded from the post-test only walking trials for the EMG amplitude normalization process. This ensured that the same electrode positioning was used for the agility and the normalization activities.

CONCLUSIONS

There were three phases to this feasibility study. We developed and confirmed our techniques for the insertion of the fEMG electrodes (Phase 1) and for collecting adequate signal from the electrodes during walking and trotting activities (Phase 2) and during dynamic agility-specific tasks (Phase 3). We present specific guidelines regarding the placement of fEMG electrodes and data collection/normalization procedures to enable investigations of muscle activation during dynamic activities in canines.
REFERENCES


**Table 1.** Electrode placement. Electrodes were positioned in the center of the mediolateral dimension of the muscle and a specific distance measured from the anatomical landmark (in cm) in the longitudinal direction. Depth of electrode insertion within the muscle relative to transverse plane is also indicated (in cm).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Shoulder Joint Position*</th>
<th>Needle Insertion</th>
<th>Electrode Placement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Anatomical Landmark</td>
<td>Position of Needle insertion</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>Flexed and externally rotated</td>
<td>Locate Supraglenoid tubercle and BB tendon</td>
<td>2 cm distal to myotendinous junction and needle directed distally into central muscle belly</td>
</tr>
<tr>
<td>Suprasinatus</td>
<td>Neutral</td>
<td>Locate cranial border of scapula</td>
<td>2 cm proximal to the cranial border of the scapula and needle directed proximally into the central muscle belly</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>Neutral</td>
<td>Locate dorsal border of scapula</td>
<td>2 cm distal to the dorsal border of the scapula and needle directed distally into the central muscle belly</td>
</tr>
<tr>
<td>Triceps Brachii Long Head</td>
<td>Neutral</td>
<td>The long head was located caudal to the caudal border of the scapula</td>
<td>Approx. ½ way between the dorsal border of scapula and the shoulder and needle directed distally into the central muscle belly</td>
</tr>
</tbody>
</table>

* All dogs were placed lying on their right side with left shoulder in neutral position, unless otherwise indicated.
Figure Legend:

1. Technique for using ultrasound to visualize and intramuscular fine-wire electrode placement. Triceps Brachii – Long Head (TBLH) is shown as an example. An ultrasound image of the location of the needle in the muscle belly (see Arrows), using B-mode, real-time ultrasonography (8 MHz micro-convex transducer, GE Healthcare Logiq P5 Ultrasound System). All needle insertions were performed by a board certified veterinary radiologist with expertise in musculoskeletal ultrasonography.

2. The final modified Ruffwear Web Master™ Harness (size Small, Ruffwear, Oregon USA) that was used for securing the wireless fEMG transducers to the dog without interfering with electrode placement. The ribcage strapping was removed and adjusted into a neck strap and the length of material covering the shoulder regions was trimmed back to prevent interference with the electrode insertion sites. Elastic strapping was sewn onto the top of the harness to hold the transducers and four separate hook and loop closure Velcro straps were attached to the harness to help keep the wires from becoming tangled together and to provide strain relief for the wires between the insertion sites and the wireless transducers.

3. Computed tomography dorsal reformatteed images with a maximum intensity projection thick slab technique (1 cm thickness), documenting the majority of the path and the tip of the fine wires during Phase 1 testing of our fine-wire electrode insertion attempts into the four shoulder muscles of interest: A. TBLH, B. BB, C. SP, and D. IF muscles. All insertions shown were made using 1.5”, 27.5 gauge hypodermic needles. The location of the electrode insertions were confirmed as appropriate for the TBLH, SP, and IF muscles. The insertion of the BB electrode (Figure 3B) shows that our attempt was unsuccessful. The length of the needle used for these insertions was determined to be too short to adequately insert the BB electrodes into the muscle bellies. Additional attempts using a 2” needle were confirmed as successful upon dissection (not shown).

4. Ensemble-averaged fEMG recordings of all four shoulder muscles comparing the pre-testing (red lines) and post-testing (blue lines) walking trials for a representative dog; A: TBLH, B: BB, C: SP, and D: IF muscles. The gait cycle is presented in percent of stride, from the initiation of left forelimb floor contact to the subsequent ipsilateral forelimb paw strike. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance.
Figure 1.
Figure 2.
Figure 4.
CHAPTER FIVE

This chapter has been prepared for publication.

An investigation to quantify muscular activation of four canine shoulder muscles in dogs performing two agility-specific tasks.

Kimberley L. Cullen, MSc; James P. Dickey, PhD; Stephen H. M. Brown, PhD; Stephanie G. Nykamp, DVM, DACVR, Leah R. Bent, PhD; Jeffrey J. Thomason, PhD; Noël M. M. Moens, MSc, DVM, DACVS

From the Biophysics Interdepartmental Group (Cullen, Dickey, Brown), the Department of Human Health and Nutritional Sciences, College of Biological Sciences (Brown, Bent), and the Departments of Biomedical Sciences (Thomason) and Clinical Studies (Nykamp, Moens), Ontario Veterinary College, University of Guelph, Guelph, ON N1G 2W1, Canada; the Institute for Work and Health, 481 University Ave, Toronto, ON M5G 2E9, Canada (Cullen); and the School of Kinesiology, Faculty of Health Sciences, University of Western Ontario, London, ON N6A 5B9, Canada (Dickey).

This manuscript represents a portion of a dissertation submitted by Ms. Cullen to the University of Guelph Biophysics Interdepartmental Group as partial fulfillment of the requirements for a Doctor of Philosophy degree.

Ms. Cullen was supported by a Natural Sciences and Engineering Research Council of Canada Graduate Scholarship.

None of the authors have any conflicts of interest to disclose regarding this manuscript.

The authors thank Ryan Frayne and Robert Caryn for their help with data collection and building the A-frame testing obstacle. We would also like to thank Leila Kelleher for her help with data collection and Peter Wegscheider for his help with building the A-frame obstacle. We also owe our thanks to Deryl Drysdale for donating two agility jumps for our testing protocol, to Sarah Hughes of Details Dog Training for donating the materials for the A-frame obstacle and to Darlene Woz of Rubber on the Run and Rochelle Hall Bagwell of American Recycling for supplying the materials and labour to make the rubber skin coating for the A-frame.

Address correspondence to Ms. Cullen (kcullen@iwh.on.ca).
ABSTRACT

Objective: The purpose of this study was to measure the level of muscular activation in four shoulder muscles while dogs performed agility-specific tasks (i.e., jumping and climbing the A-frame) and to evaluate the relationship between level of muscular activation and the risk of injury for each type of task.

Methods: We measured muscle activation in eight healthy, client-owned agility dogs using ultrasound-guided fine-wire electromyography (fEMG) of four specific shoulder muscles: Biceps Brachii (BB), Supraspinatus (SP), Infraspinatus (IF), and Triceps Brachii – Long Head (TBLH), while dogs performed a two jump sequence and while dogs ascended and descended an A-frame obstacle at two different competition heights currently in use in the sport.

Results: Our findings indicate that jumping is an especially demanding activity for dogs in agility, requiring the highest level of shoulder muscle activation compared to ascending and descending an A-frame. There is no difference in muscle activation amplitudes required between the two most common A-frame heights used in competitions. Preliminary findings suggest that there may be differences in amplitudes of muscle activation for dogs that are trained to run vs. stop on the final descent of an A-frame.

Conclusions: This study helps shed light on how the shoulder muscles function during specific agility-related tasks associated with a high risk of injury. This study also provides information broadly relevant to understanding the pathophysiology of shoulder injuries related to canine athletic activity.
INTRODUCTION

Canine agility is a team sport that has grown increasingly popular over the last decade.\textsuperscript{1,2} In recent years, there has been tremendous growth in the number of dogs participating in the sport across North America. For example, in 2012 the number of dog entries to sanctioned American Kennel Club (AKC) agility events was over 1.1 million, at a growth rate of nearly 10% annually over the last ten years.\textsuperscript{2}

It is also a physically demanding sport for both the dog and handler. A recent commissioned study conducted by researchers at the University of Massachusetts for a local agility training facility, found that the heart rate and metabolic responses for the human when running an agility course is equivalent to moderate to vigorous physical activity.\textsuperscript{3} Another physiological study looking at the hematologic and biochemical changes in dogs participating in agility events, found responses consistent with high-intensity anaerobic exercise.\textsuperscript{4}

As there is in any sport, there is an inherent risk of injury to the canine participants. Soft tissue injuries such as strains, sprains and contusions are
relatively common in agility; approximately 32% of dog athletes develop an injury\textsuperscript{5,6} and the biomechanical mechanism of injury is often unknown.\textsuperscript{6} However, certain activities, such as jumping and climbing the A-frame obstacle, have a higher risk for injury.\textsuperscript{5,6} The shoulder has been identified in two recent retrospective surveys, as the most frequently injured anatomical location.\textsuperscript{5,6}

With these increasing rates of participation, and the knowledge that nearly one-third of agility dogs experience injuries in the sport, there is also a growing interest in understanding the pathophysiology of shoulder lameness resulting from participation. Canine shoulder injuries are particularly difficult clinical challenges. The soft tissues covering the joint make palpation difficult and the degrees of freedom of movement across the joint complicate diagnosis.\textsuperscript{7} Although case reports and surgical techniques are frequently reported, few biomechanical studies describe the normal kinematic, muscular activation or kinetic features of canine gait; a recent editorial reported that the state of the art for analysis of fundamental biomechanics in canines is decades behind human and equine science.\textsuperscript{8}

Biomechanical tools such as force plates, electromyography and motion-capture systems have been applied to study canines as models of human disease such as osteoarthritis,\textsuperscript{9–11} and in canine companion animals.\textsuperscript{12} Normal muscle function in healthy canines has been examined at a walk,\textsuperscript{13–15} trot,\textsuperscript{16–20} and gallop.\textsuperscript{21} Several biomechanical studies have examined clinical canine populations including: partial and pancarpal arthrodesis,\textsuperscript{22} osteoarthritis,\textsuperscript{23–25}
cranial cruciate ligament rupture\textsuperscript{26} and hip dysplasia.\textsuperscript{27,28} However, limited research has evaluated the biomechanics of canine sport and agility.\textsuperscript{29–31}

Although it is well understood that injury occurs when tissue loads exceed tissue tolerance, the link between reports of injury and causes/mechanisms is often elusive;\textsuperscript{32} one systematic framework suggests that it is important to first establish the incidence and severity of the injury problem and then establish the aetiology and mechanism of injury through biomechanical studies,\textsuperscript{32} together these studies build a foundation for developing prevention strategies.\textsuperscript{32} The literature to date has emphasized the need to conduct studies to examine the likely mechanisms of injury within this sport; the current study represents the follow-up to our initial survey\textsuperscript{6,33} in which we begin to evaluate the biomechanical factors related to shoulder injury in the specific agility components of jumping and ascending/descending the A-frame.

The purpose of this study was to measure the muscular activation in four shoulder muscles continuously while dogs performed agility-specific tasks (i.e., jumping and climbing the A-frame) and to evaluate the relationship between level of muscular activation and the risk of injury for each type of obstacle. The four shoulder muscles examined in this study were chosen both for their recognized importance in canine locomotion\textsuperscript{13,16,21,34} and for their frequency of observation in canines presenting with forelimb lameness in clinical settings.\textsuperscript{7,35} These muscles included the Biceps Brachii (BB), Supraspinatus (SP), Infraspinatus (IF), and Triceps Brachii – Long Head (TBLH).
Two specific questions were addressed. The first question we posed was: 

*Is there a difference in PEAK EMG amplitude when dogs are jumping vs. ascending/descending the A-frame at two different competition heights?* We were interested in learning whether there would be differential changes in the magnitude of shoulder muscle activation when completing the jumping task compared to the A-frame tasks. In addition to examining ascending and descending the A-frame separately, we also compared two current competition heights of the A-frame, where the apex was set at either 1.75 m (69”, high) or 1.67 m (66”, low). There is an ongoing debate within the agility community about the best height for dogs to perform the A-frame to reduce the risk of injury. Most agility organizations throughout the world have changed their rules governing A-frame apex height to one of these two heights over the last five years.\(^{36–39}\)

The second question examined was: *Is there a difference in Peak EMG amplitude for running or stopped contact performance when descending an A-frame at the two different competition heights?* When dogs perform the A-frame task, there are two current training techniques employed by handlers to teach their dogs to perform this obstacle. Handlers typically choose either to teach their dogs to come to a complete stop at the bottom of the down ramp with the two forelimbs resting on the ground, while the two hind limbs remain in touch with the A-frame ramp (stopped contact performance); or to run through the full length of the down ramp without stopping and thus carrying forward towards the next obstacle in the sequence without a break in momentum (running contact performance). Regardless of training technique employed, the dog is required to
place at least one paw in the final third of the down ramp (i.e., the last 0.9 – 1.1 m or 36 - 42 in. of the board depending on the governing association). Failure to do so results in the accumulation of a performance fault added to their score for that round. The dog that accumulates the fewest faults with the fastest time is declared the winner of the class. It is believed that dogs trained to stop are less likely to incur a performance fault on this obstacle, but that dogs that are trained to run generate a time advantage which could help them complete the task more quickly. There is an ongoing debate in the agility community regarding which of these techniques (run vs. stop) is safer for the dogs. We were interested in examining whether there were differential changes in the magnitude of shoulder muscle activation between these two training techniques for descending the A-frame.

This study helps shed light on how the shoulder muscles function during specific agility-related tasks that are known to be associated with high risk of injury.

METHODS

Muscle activation was measured using ultrasound-guided fine-wire electromyography (fEMG) of four specific shoulder muscles: Biceps Brachii (BB), Supraspinatus (SP), Infraspinatus (IF), and Triceps Brachii – Long Head (TBLH). Video recordings were used to evaluate the sequence and timing of the various activities. The fEMG techniques are well-established and have been used in neurophysiological and biomechanical studies in humans since the early 1960s and in dogs for the past 30 years.
**Participants**

Eight healthy, client-owned border collies (*Canis lupus familiaris*) with a minimum of two years agility experience were used in this study to record fEMG activity of four specific shoulder muscles: BB, SP, IF, and TBLH.

All dogs were evaluated using two independent orthopedic examinations (limb palpation and gait analysis at a walk and at a trot). These examinations were performed by a board certified veterinary surgeon with experience in kinetic and kinematic gait analysis to assure that the dogs were clinically normal.

**Method of recruitment and consent**

All procedures were approved by the University of Guelph’s Animal Care Committee’s animal utilization policies. Healthy client-owned agility dogs were recruited from the local agility community. A flyer describing the study and providing a method of contacting the study coordinator was circulated at agility competitions within the Southwestern Ontario agility community in the Fall of 2012. Interested handlers who contacted the study investigators were provided with an information sheet about the study and the opportunity to discuss the experimental protocol in more detail with the study coordinator. Those handlers that verbally consented to participate were scheduled to bring their dogs to the gait analysis laboratory for testing; at which time, the handlers provided their written informed consent.
Electromyography

Electrode preparation

The thin and flexible intramuscular fEMG electrodes (two wires, each 100µm diameter stainless steel 316 insulated with Formvar; California Fine Wire, Grover Beach, CA, USA) were prepared by forming a loop of wire and threading the ends down the bore of a 1.5” (SP, IF, TBLH) or 2” (BB), 27.5 gauge hypodermic needle and then cutting the tip of the loop. A small section (~ 5 mm) of Formvar insulation from the tip of each electrode wire was removed and the tips were offset with respect to each other and then bent around the edge of the needle to form a barb. These assemblies were sterilized by steam autoclave.

Skin Preparation

The BB, SP, IF, TBLH muscle bellies were located by manual palpation. The surface of the skin was prepared for ultrasound with isopropyl alcohol. The skin was anaesthetized using Emla cream (at 1.5g/10cm², Astra-Zeneca, Sweden) to eliminate discomfort as the needle penetrated the skin; no discomfort persisted following removal of the needle. Bare skin of the inner left thigh was exposed by trimming a 2cm by 2cm patch of hair with a clipper; a surface electrode (pre-gelled, Ag-Ag/Cl, 10mm inner diameter, MediTrace 130, Kendall, MA, USA) was placed here to provide a ground reference.

Ultrasonographic Examination

We performed B-mode, real-time ultrasonography over the pectoral muscles of interest to guide the needle insertion of the fine wire electrodes (8
MHz micro-convex transducer, GE Healthcare Logiq P5 Ultrasound System). All insertions were performed by a board certified veterinary radiologist with expertise in musculoskeletal ultrasonography.

**Electrode Insertion**

All electrodes were placed into the muscles of interest on the left side of the dog. Anatomical landmarks were used to determine the needle insertion point and the insertion direction, which have been previously reported. Dogs were placed lying down on their right sides with the left shoulder in neutral position for all insertions except for the BB. To facilitate access to the BB muscle belly, the dog’s left forelimb was passively restrained with the elbow extended, the shoulder flexed and externally rotated. Each needle/EMG electrode was limited to one use. The fine-wire electrodes were inserted using the hypodermic needle, which was retracted immediately following insertion. A surface electrode was used to ground the system and was placed on the left inner thigh. The wires were connected to the amplifier modules (Trigno Wireless Sensors, Delsys, Boston MA, USA), leaving a loop of excess wire as strain relief, and were secured via a harness to the dog.

**Video Camera**

Videographic data of all trials were collected using a 30 Hz digital video camera (Canon Vixia HFM31). The video records were synchronized with the EMG data using a pulse that was recorded together with the EMG and turned on
a light in the video frame. The timing of the "paw down" stride events in the fEMG signals was extracted from the corresponding video records.

Harness

A Ruffwear Web Master™ Harness (size Small, Ruffwear, Oregon USA) was modified to meet the requirements for securing the wireless fEMG transducers to the dog without interfering with electrode placement. Dogs were fitted with the harness prior to fEMG electrode insertions. Further details regarding the modifications made to the harness, and a figure showing the final harness have been presented elsewhere.\(^{42}\)

Procedures

Data were recorded during locomotion of the dog using the following protocol:

1) Baseline measures: three successful trials were recorded at a walk while the dog covered a back-and-forth pattern of a 6 m (20’) distance.

2) Ascending/Descending the A-frame (2 height conditions): six trials were recorded with the dog running up the A-frame with the apex set at 1.67 m (66") and 1.75 m (69”). At both heights, three trials were performed with the camera on the ascending side of the A-frame and three were performed with the camera on the descending side. The presentation order for performance height was alternated for each participant, although the ascending task always preceded the descending task. The dog was left a minimum distance of 4.5 m (15’) from the A-frame and began the task by running towards the A-frame when initiated by the
handler. After running up the A-frame, the dogs continued over the apex (as per usual agility performance of this obstacle) and exited the A-frame out of the cameras' field of view. Dogs could continue off the A-frame a minimum of 4.5 m (15') at the end of this task.

3) Jumping task: three successful trials were recorded with the dog performing two consecutive bar jumps spaced 4.5 m (15’) apart set at 55cm (22”) from the ground. The dog was left a minimum distance of 4.5 m (15’) from the first jump and began the task when initiated by the handler.

4) Repeat of baseline measures: three successful trials were recorded with the dog repeating the walking task.

After data collection, the transmitters, harness and fEMG wires were removed and the dogs left the laboratory with their owners.

Data Management and Analysis

EMG Signal Collection and Processing

The EMG signals were wirelessly transmitted to the receiver (Delsys, Boston MA, USA), amplified by a factor of 909, with a full dynamic range of +/- 5V, sampled at 2000 Hz, digitized with a 16 bit A-D converter (National Instruments, USB6225), visually displayed for quality assurance and stored for off-line analysis. The EMG signals were band-pass filtered between 100-500 Hz with a 2nd order Butterworth filter, rectified and low-pass filtered at 3 Hz with a 2nd order Butterworth filter to remove low frequency movement artifact and
high frequency noise in accordance with established procedures\textsuperscript{44} and ISEK guidelines.\textsuperscript{45}

Stride Normalization

Time-normalized stride average EMGs were generated for each muscle site for each stride event (i.e., pre-transition, transition, and post-transition) and for each agility-specific task (i.e., Jumping, Ascending A-frame, Descending A-frame; see Figure 1-6). To enable averaging of multiple strides across trials and for comparisons across participants and stride events, each EMG sample was time-normalized to percent of stride (i.e., 100 data points) using a custom-written LabVIEW program.

Amplitude Normalization

EMG samples for each stride were normalized against the average PEAK amplitude recorded during the three post-experiment baseline control walking trials. This normalization technique has been shown to minimize inter-subject variability in human gait analysis.\textsuperscript{46,47}

Defining Individual Strides

Walking Task: For the walking task (baseline condition), which was used for amplitude normalization, the recorded video was used to identify the timing in the EMG signal that corresponded to “paw down” or the initiation of left forelimb support for each stride until the next consecutive “paw down” event for this limb.
These individual trials were normalized to 100 percent of stride duration and ensemble-averaged.

**Agility-specific Tasks:** For each of the agility-specific tasks, three stride events of interest were identified and were generated from EMG signals using a sampling window that began and ended with left forelimb paw contact. Again, the recorded video was used to identify the timing in the EMG signal that corresponded to “paw down” for each stride event and these individual trials were rubber-banded to 100 percent of stride and ensemble averaged.

The three stride events of interest were labeled as 1) the pre-transition stride, 2) the transition stride, and 3) the post-transition stride. For the jumping task, the transition stride was defined as the stride where the dog lifted off the ground and jumped over the bar until landing. For the ascending A-frame tasks, the transition stride was defined as the stride at which the dog lifted off the ground until paw down on the A-frame ramp. For the descending A-frame tasks, the transition stride was defined as the stride where the dog left the A-frame and landed on the ground. The pre- and post-transition strides were defined in all cases as the previous and following forward moving stride in sequence for the transition stride respectively.

All EMG samples were screened by visual inspection and assessed for quality of recording using a custom-written LabVIEW (National Instruments, Austin TX, USA) program at both the pre-processing and post-processing stages. Recordings that contained high levels of artifact, which could not be adequately
removed with signal filters, were excluded from analyses as these samples may have led to a false interpretation of muscle activation (111 of 3645 stride events were excluded in this way).

**Descriptive and Statistical Analyses**

1. **Descriptive Analysis of Muscle Activity**

   The following temporal and activation level parameters were examined independently for all four muscles sites for the walking task and for the agility-specific tasks:

   (1) Time to peak muscle activity
   (2) Peak muscle activity
   (3) Percent of stride in stance

2. **Differences in Muscle Activity across Agility-specific Tasks**

   A linear mixed effect model was used to answer the first research question for each muscle site independently: *Is there a difference in PEAK EMG amplitude when dogs are jumping vs. climbing up/down A-frame?* The model was set with two factors: condition [5 levels: 1. Jump (j_NA), 2. Up – low apex (u_low), 3. Up – high apex (u_high), 4. Down - low apex (d_low), 5. Down – high apex (d_high)] x stride [3 levels: pre-transition stride (stride-1), transition stride (stride_0) and post-transition stride (stride_1)]. When indicated, *post hoc* testing was conducted using least squared means differences. Statistical significance was set at p<0.05.
Based on the visual inspection of results from this analysis, a secondary, exploratory analysis was conducted examining whether there were differences in muscle activity in the jump task between the first and second jump based on number of strides taken before Take-off: The models were set with one factor: jump [2 levels: 1. Jump 1 (stride_0), 2. Jump 2 (stride_5)].

3. Differences in Muscle Activity between Contact Performance when Descending the A-frame

A linear mixed effect model was used to answer the second research question for each muscle site independently: Is there a difference in Peak EMG amplitude for running or stopped contact performance when descending an A-frame? The model was set with two factors: condition [2 levels: 1. Down - low apex (d_low), 2. Down – high apex (d_high)] x contact performance [2 levels: running contact (run), stopped contact (stop)]. When indicated, post hoc testing was conducted using least squared means differences. Statistical significance was set at p<0.05.

RESULTS

The eight border collies (four males, four females) that were used in this study were all highly-trained agility dogs with a minimum of two years competing in agility and a mean age of 5.4 ± 1.9 years. The average weight of the sample was 15.6 ± 2.1 kg and average height was 50.7 ± 1.8 cm. Five of these dogs were trained to perform the A-frame using a stopped contact performance and three were trained to run off the exit of the A-frame.
Table 1 presents the number of usable fEMG recordings for the analyses (after low quality signals were removed) by participant, muscle site, stride event, agility-specific task, and contact performance. As can be seen in the table, there were a low number of IF muscle fEMG recordings available for use in these analyses.

1. Descriptive Analysis of Muscle Activity

Data for representative participants (Figures 1-6) and sample mean peak activation amplitudes (Table 2) illustrate typical muscle activation patterns during the walking and the agility-specific tasks. During the walking trials, the pattern of activation for the four shoulder muscles were consistent with previous studies. The TBLH became active during mid- to late-stance as the shoulder is flexed and the elbow is extended through the stance phase. The muscle’s activation declines throughout the swing phase of the gait cycle (See Figure 1A). The BB was active during early stance and then again at terminal stance, with peak activity observed during swing as the elbow is flexed and shoulder extended in preparation for paw contact (See Figure 1B). The SP muscle is active as the shoulder is advanced forward over the limb in early stance and then activity declines until late swing as the shoulder is extended forward in preparation for the initiation of the next stance phase (See Figure 1C). The IF muscle is also active in early stance to stabilize the shoulder as limb support is initiated. It is also active in late-stance through mid-swing, supporting the scapula to prevent shoulder abduction during this phase of the gait cycle (See Figure 1D).
Across all agility tasks, and many stride events, the four shoulder muscles demonstrated their peak activation levels during the swing phase of the gait cycle. The pattern of activation for the shoulder flexor (TBLH), shoulder stabilizers (SP, IF), and the shoulder extensors (BB, SP) were consistent with expectations based on their function and anatomical locations.\textsuperscript{13,16,21,34}

1.1 Descriptive analysis of muscle activation patterns during the jumping task

In the jumping task (see Table 2 and Figure 2), the peak activations across all four muscles was substantially greater than that observed during the baseline walking task, ranging from 2.7 times walking (BB stride\(_1\)) to more than 10.6 times walking (TBLH stride\(_0\)). The transition from stance to swing occurred early in the timing of the stride for all stride events in the sequence (transition strides: 12\% for stride\(_0\), 16\% for stride\(_5\); post-transition strides: 31\% for stride\(_1\), 36\% for stride\(_6\)). The first pre-transition stride was nearly equally split between stance and swing (stride\(_1\): 49\% of stride in stance). Across all four muscles, peak activation occurred during swing phases, except for the transition strides (stride\(_0\) & stride\(_5\)), where all muscles tended to have two peaks, one at early stance and a second during mid-swing.

1.2 Descriptive analysis of muscle activation patterns during the ascending A-frame tasks

Similarly to jumping task, the peak activations across all four muscles was substantially greater than that observed during the baseline walking task in both of the ascending A-frame tasks (See Table 2 and Figures 3 (high apex) and 4
(low apex)), ranging from 2.8 times walking (SP stride-1, u_low) to more than 7.4 times walking (IF stride-1, u_low). In both tasks involving ascending the A-frame, the transition from stance to swing occurred early in the stride for all stride events and was virtually identical in timing between the high and low apex A-frame heights (stride-1: 26% u_high and 25% u_low; stride_0: 25% u_high and 25% u_low; and stride_1: 32% u_high and 33% u_low). Across all four muscles, peak activation occurred in the swing phase of the strides.

1.3 Descriptive analysis of muscle activation patterns during the descending A-frame tasks

The peak activations across all four muscles continued to be higher than that observed during the baseline walking task in both of the descending A-frame tasks (See Table 2 and Figures 5 (high apex) and 6 (low apex)), ranging from 1.7 times walking (TBLH stride_1, d_high) to more than 7.6 times walking (IF stride-1, u_low). In both tasks involving descending the A-frame, a greater proportion of the stride was spent in stance for all stride events as compared to the jumping and ascending A-frame tasks (stride-1: 63% d_high and 66% d_low; stride_0: 57% d_high and 59% d_low; and stride_1: 41% d_high and 37% d_low). Also, different than the other agility tasks, peak activation occurred in stance for a greater number of stride events for the descending A-frame tasks. The BB and SP muscles demonstrated peak activation during stance consistently across all three stride events at both A-frame heights. The IF muscle also demonstrated peak activation during stance for the transition stride (stride_0) across both A-
frame heights. The peak activation for the TBLH muscle remained in swing across all strides and A-frame heights for these tasks.

2. Differences in Muscle Activity across Agility-specific Tasks

The interaction plots for agility-specific task by stride event are presented in Figure 7 for each muscle site, which are reported in sections 2.1-2.4 below.

2.1 Muscle 1 (TBLH)

There was a significant interaction between condition and stride (p<0.0001). Post hoc tests revealed that TBLH activation is highest while jumping (stride_0, peak activity occurs at 39.0% of stride, swing begins at 18.5%) and lowest while descending an A-frame regardless of height during the pre-transition stride (stride-1). The remainder of conditions and strides are not significantly different from one another (see Figure 7A).

2.2 Muscle 2 (BB)

There was a significant interaction between condition and stride (p<0.0001). Post hoc tests revealed that BB activation is highest while jumping (stride_0, peak activity occurs at 36.8% of stride, swing begins at 18.5%) and lowest while landing from a jump (stride_1). It is also low when descending an A-frame regardless of height during the pre-transition stride (stride-1). The remainder of conditions and strides are not significantly different from one another (see Figure 7B).
2.3 Muscle 3 (SP)

There was a significant interaction between condition and stride \((p=0.009)\). Post hoc tests revealed that SP activation is highest while leaving an A-frame regardless of height (\(\text{stride}_1\), \(d_{\text{high}}\): peak activity occurs at 40.5% of stride, swing begins at 33.5%; \(d_{\text{low}}\): peak activity occurs at 39.7% of stride, swing begins at 36.6%). It is also high for the transition strides when descending an a-frame and when jumping (\(d_{\text{high}}/d_{\text{low}}/j_{\text{NA}}\) \(\text{stride}_0\)). It is lowest while landing from a jump (\(\text{stride}_1\)). It is also low for all pre-transition stride (\(\text{stride}-1\)) and when ascending the a-frame (transition and post-transition strides: \(u_{\text{high}}/u_{\text{low}}\) \(\text{stride}_0\) and \(\text{stride}_1\)). The remainder of conditions and strides are not significantly different from one another (See Figure 7C).

2.4 Muscle 4 (IF)

The interaction between condition and stride was not-significant \((p=0.2)\). The main effect for condition is trending towards significance \((p=0.055)\). Inspection of the means showed that ascending the A-frame (all strides) required the highest level of IF activation (greater even than for \(j_{\text{NA}}\) \(\text{stride}_0\)). The descending pre-transitions strides continued to require the least activation in this muscle, consistent with the other muscles. The remainder of conditions and strides are not significantly different from one another (see Figure 7D).

2.5 Secondary jumping analysis

Visual inspection of the transition strides for jump 1 (\(\text{stride}_0\)) and jump 2 (\(\text{stride}_5\)), revealed what appeared to be a pattern for several dogs in that the
first jump had a higher peak amplitude compared to the second jump (See Figure 2). When examined statistically, this turned out not to be the case (TBLH: p=0.14, BB: p=0.22, SP: p=0.14, IF: p=0.27).

Dogs were able to self-select how many pre-jump strides they took before taking off. Although we didn’t set out to evaluate this a priori, we examined the results to explore this finding in more detail. The jumping trials were reexamined to categorize each jump in the sequence by the number of pre-transition strides taken before taking off (i.e., 0, 1 or 2 pre-strides taken before jumping). These results are presented in Figure 8 for each muscle site. There does appear to be a difference in peak muscle activity when taking into account the number of pre-strides taken before lift-off; however there were not enough data points to run a statistical analysis.

3. Differences in Muscle Activity between Contact Performances on the A-frame

There was only a main effect for contact performance found for the SP muscle (p=0.03). SP activity is higher for dogs that stop compared to dogs that run when leaving the A-frame (see Figure 9). There was no significant differences in muscle activation found between dogs with running contacts compared with dogs with stopped contacts in the other three muscles (TBLH: p=0.55, BB: p=0.54, IF: p=0.18).
DISCUSSION

This study described the activation patterns of four shoulder muscles for highly-trained agility dogs completing three agility-specific tasks. The results have provided the first in vivo recordings of these muscles in dogs using a minimally invasive, ultrasound-guided fEMG insertion technique. Previous studies in dogs either did not use ultrasound to guide the insertion,\textsuperscript{13,16,21} or employed a surgical implantation technique.\textsuperscript{18,19,34,48,49}

1. Descriptive Analysis of Muscle Activity

Across each of the agility-specific tasks, the magnitudes of the peak activations for all four shoulder muscles were consistently high relative to walking (See Table 2). The TBLH demonstrated peak activations during the agility tasks between 3 and 10 times that observed during walking. A similar pattern was observed for the other three muscles (BB, SP, and IF) although the range in activations was slightly smaller for these muscles, ranging from 3 to 6 (BB & SP) or 7 (IF) times the peak activation observed during walking.

In this study, we used a submaximal dynamic task (i.e., walking) as a reference activity for EMG normalization, in order to compare activation patterns across muscles and different agility-specific tasks. Although there is debate in the literature regarding the best normalization technique to use under similar conditions (i.e., when it is impractical to acquire muscle activations from a reference maximal voluntary contraction), this technique has been used successfully to allow direct comparisons between subjects and within-subjects across tasks and testing dates.\textsuperscript{50–54} However, a drawback to this technique is that
it is difficult to identify at what percentage of the maximal capacity the muscles were performing, or information regarding the relative contributions among the different muscles during these agility-specific tasks. From our previous work, we have learned that the shoulder is susceptible to injury, especially when jumping and performing the A-frame obstacle.\textsuperscript{6,33} With this study, we have been able to shed light on the relative magnitude of activation across four shoulder muscles when performing agility-specific tasks, several of which are commonly injured in this population.\textsuperscript{7,35} Future work can expand this knowledge by including additional kinematic and kinetic parameters while performing these highly-specific agility tasks.

In the majority of stride events across all four muscles, peak activation was recorded in the swing phase of the gait cycle. Recent work examining the mechanism of human hamstring injuries in over-ground sprinting have demonstrated there is a substantial potential for injury in this powerful extensor muscle during terminal swing.\textsuperscript{55–57} Using whole-body kinematics, ground reaction forces and EMG recordings, researchers have determined that hamstring muscles exhibit eccentric contractions during the late swing phase of over-ground sprinting\textsuperscript{55–57} and the maximum activations of the hamstring muscle occurred during terminal swing.\textsuperscript{56,57} Eccentric contractions are known to contribute to injury,\textsuperscript{58} and have been associated with significant declines in maximum force output, histological, and structural evidence of damage.\textsuperscript{59} Animal models have shown that the best indicator of muscle damage is the magnitude of the muscle fiber active strain (i.e., strain that occurs as the active muscle is
lengthened) during contraction.58,60,61 In light of these findings, future work could utilize kinematic and ground reaction forces, in addition to EMG measures, building linked-segment models to examine the musculotendon dynamics in these shoulder muscles during these specific agility tasks. Attention could be given to the differences in peak activation levels between stance and swing phases in relation to the timing of eccentric and concentric contractions of these muscles. This would further our understanding of the specific etiologies of injuries related to jumping and climbing the A-frame in agility, and help identify which shoulder muscles are at a greater risk for injury within the sport.

For both the jumping and ascending the A-frame tasks, a larger proportion of the stride was spent in swing for all stride events (i.e., pre-transition, transition and post-transition events). However, during the two descending tasks, the stance time was longer than swing time for both the pre-transition and transition strides. Additionally, peak activation for the shoulder extensor (BB, SP) and stabilizer (SP, IF) muscles occurred during stance for these stride events. This change in gait timing is consistent with the expectation that the forelimbs will exert stronger braking forces during downhill grades to facilitate anterior-posterior balance.62,63

2. Differences in Muscle Activity across Agility-specific Tasks

The results from this analysis indicate that the jumping transition stride (stride_0) consistently requires the highest level of muscle activation across all four shoulder muscles compared to ascending or descending an A-frame and is most demanding for the TBLH muscle overall. The pre-transition strides (stride-1)
when descending an A-frame consistently required the least activation across all muscles sites, irrespective of apex height.

Across all agility-specific tasks, there appears to be the most consistency in muscle activation patterns (i.e., least amount of stride to stride variability) when ascending the A-frame, regardless of height. Within the descending the A-frame task, the post-transition stride (stride_1) always required the highest amount of activation among all four muscles. Although only trending to significance, for the IF muscle, ascending the A-frame was as demanding as the jump condition. There was no appreciable difference in the muscle activation patterns between the two A-frame competition heights for both ascending and descending tasks across all muscle sites.

Our previous work has indicated that shoulders are at the highest risk for injury when jumping or performing the A-frame task. Based on the findings from this study, it is clear that, at least in terms of levels of muscle activation, the jump task – and more specifically the transition stride, where the dog lifts off the ground to clear the jump and reaches forward with the forelimb to land, is consistently the most demanding across all four shoulder muscles. In regards to the A-frame task, ascending the A-frame is consistently more demanding for the dog across all muscles than descending the A-frame, with the exception of the final descent stride (i.e., the post-transition stride) after the forelimbs have already touched down on the ground.
Another interesting finding was the consistency in muscle activation patterns between the two A-frame competition heights tested in this study. Within the agility community, there is much discussion about whether there is an increased risk of injury for the dogs when performing an A-frame set at the higher of these two heights. While our results can not speak fully to the risk of injury without considering joint and muscle forces and moments while performing these tasks, we have clearly documented that there is no appreciable difference between these two competition heights in regards to the levels of muscular exertion in these four specific muscles that is required to complete them.

3. Differences in Muscle Activity between Contact Performances on the A-frame

The only statistically significant difference between contact performance type (run vs. stop) was found for the SP muscle. There is a higher demand on the SP muscle for dogs that are trained to stop on the A-frame compared to dogs that are trained to run off the down ramp. While not statistically significant, the running technique seems to be most demanding for TBLH and IF while the stopping technique is also more demanding for the BB, similar to our finding for the other shoulder extensor examined in this study, the SP.

The fact that there were no significant differences between contact performance type for the other three muscles should be interpreted with caution. Due to the low numbers of data points available for this analysis after removing trials with low signal quality, the models were actually underpowered to find
statistically significant differences in TBLH, BB and IF. Future studies should explore this further with larger sample sizes.

Study Limitations and Strengths

As shown in Table 1, there was a large proportion of the IF muscle fEMG recordings which were excluded from analyses due to poor signal quality. It is unclear what led to this result. One possible explanation could be that the insertion site for the IF rested underneath the harness structure that the participants were fitted with to secure the fEMG wires. Future studies should consider alternate harness arrangements that allow the wires to remain easily fixed without potentially interfering with the signal quality due to contact.

This study examined muscle activation patterns in four shoulder muscles during three highly dynamic agility-specific tasks. Shoulder injuries are known to be associated with performance of these tasks,\textsuperscript{5,6} however, the results from this study, while insightful, only offer one piece of the puzzle in understanding the mechanisms of injury related to these tasks. Future work investigating the kinematic joint positions in space and ground reaction forces during these stride events and more specifically, building link-segment models using these measures are necessary to help shed light on the injury mechanisms related to these agility tasks. Researchers in the UK\textsuperscript{29} examined ground reaction forces in dogs performing different jumping tasks and observed high peak vertical forces in the forelimbs (4.5 times body weight) when performing a similar jumping task to the one conducted in our experiment. In their study, dogs were asked to jump 10 cm higher than in our protocol, representing a difference in typical height.
jumped between agility competitions in these two jurisdictions. To date, there have been no studies reporting on the kinetics related to the A-frame task. Sophisticated computer models have been developed to predict hind limb loading during walking and trotting,\textsuperscript{64,65} and two-dimensional (2D) models have been developed for the pectoral limb during walking.\textsuperscript{66} With these additional data, we could develop similar models to predict the risks of shoulder injury related to these agility-specific activities.

This study successfully described the activation patterns of four shoulder muscles for highly-trained agility dogs completing highly dynamic activities. The results have provided the first \textit{in vivo} recordings of these muscles in dogs using a minimally invasive, ultrasound-guided fEMG insertion technique. The use of intramuscular electrodes is preferred as the problems of electrode movement relative to the muscle and cross-talk from adjacent muscles are minimized when the use of surface electrodes is avoided.\textsuperscript{43,44,67}

**Conclusions**

Our findings suggest that jumping is an especially demanding activity for dogs in agility, requiring the highest level of shoulder muscle activation compared to ascending and descending an A-frame. There does not appear to be any difference in muscle activation required between the two most common A-frame heights used in competitions. Preliminary findings suggest that there may be differences in muscle activation patterns for dogs that are trained to run vs. stop on the final descent of an A-frame. Additionally, it appears that the number of pre-jumping strides before dogs leave the ground when jumping may affect the
muscle activation patterns. Future work should build on these findings to help shed light on the mechanisms related to shoulder injuries associated with these specific agility tasks.
REFERENCES


Table 1. Frequency distribution of usable fEMG recordings (n=384) by participant, muscle site, stride event, agility-specific task, and contact performance type. In each comparison, the total number of available fEMG recordings are represented.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Number of Valid fEMG Recordings (n=384)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Participant</strong></td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>59</td>
</tr>
<tr>
<td>D2</td>
<td>24</td>
</tr>
<tr>
<td>D3</td>
<td>52</td>
</tr>
<tr>
<td>D4</td>
<td>45</td>
</tr>
<tr>
<td>D5</td>
<td>45</td>
</tr>
<tr>
<td>D6</td>
<td>45</td>
</tr>
<tr>
<td>D7</td>
<td>58</td>
</tr>
<tr>
<td>D8</td>
<td>56</td>
</tr>
<tr>
<td><strong>Muscle site</strong></td>
<td></td>
</tr>
<tr>
<td>Muscle 1 (TBLH)</td>
<td>115</td>
</tr>
<tr>
<td>Muscle 2 (BB)</td>
<td>115</td>
</tr>
<tr>
<td>Muscle 3 (SP)</td>
<td>102</td>
</tr>
<tr>
<td>Muscle 4 (IF)</td>
<td>52</td>
</tr>
<tr>
<td><strong>Stride event</strong></td>
<td></td>
</tr>
<tr>
<td>Pre-transition stride (stride-1)</td>
<td>123</td>
</tr>
<tr>
<td>Transition stride (stride_0)</td>
<td>131</td>
</tr>
<tr>
<td>Post-transition stride (stride_1)</td>
<td>131</td>
</tr>
<tr>
<td><strong>Agility-specific task</strong></td>
<td></td>
</tr>
<tr>
<td>Down – High apex (d_high)</td>
<td>74</td>
</tr>
<tr>
<td>Down – Low apex (d_low)</td>
<td>79</td>
</tr>
<tr>
<td>Jump 1 (j_NA)</td>
<td>72</td>
</tr>
<tr>
<td>Up – High apex (u_high)</td>
<td>79</td>
</tr>
<tr>
<td>Up – Low apex (u_low)</td>
<td>80</td>
</tr>
<tr>
<td><strong>Contact Performance</strong></td>
<td></td>
</tr>
<tr>
<td>Running contact (run)</td>
<td>58</td>
</tr>
<tr>
<td>Stopped contact (stop)</td>
<td>95</td>
</tr>
</tbody>
</table>
Table 2. Mean peak muscle activation for the TBLH, BB, SP, and IF muscles for the pre-transition (stride-1), transition (stride_0) and post-transition stride (stride_1) events for each agility-specific task.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Agility-specific Task</th>
<th>d_High</th>
<th>d_Low</th>
<th>j_NA</th>
<th>u_high</th>
<th>u_low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stride-1</td>
<td>Stride_0</td>
<td>Stride_1</td>
<td>Stride-1</td>
<td>Stride_0</td>
<td>Stride_1</td>
</tr>
<tr>
<td>Muscle 1 (TBLH)</td>
<td>Peak amplitude</td>
<td>3.1</td>
<td>4.7</td>
<td>7.6</td>
<td>2.9</td>
<td>4.1</td>
</tr>
<tr>
<td>Muscle 2 (BB)</td>
<td>Peak amplitude</td>
<td>3.1</td>
<td>4.1</td>
<td>4.6</td>
<td>3.1</td>
<td>3.6</td>
</tr>
<tr>
<td>Muscle 3 (SP)</td>
<td>Peak amplitude</td>
<td>3.1</td>
<td>5.0</td>
<td>5.8</td>
<td>3.6</td>
<td>5.0</td>
</tr>
<tr>
<td>Muscle 4 (IF)</td>
<td>Peak amplitude</td>
<td>1.7</td>
<td>5.2</td>
<td>6.0</td>
<td>2.6</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Peak amplitudes reported in this table have been normalized to the walking trials and should be interpreted as being x times that of the peak amplitude observed in the walking trials.
FIGURE LEGENDS

1. Ensemble-averaged fEMG recordings of all four shoulder muscles observed during the post-experiment walking trials for a representative dog; A: TBLH, B: BB, C: SP, and D: IF. The gait cycle is presented in percent of stride, from the initiation of left forelimb floor contact to the subsequent ipsilateral paw strike. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. ST = Stance Time and SW = Swing Time.

2. Ensemble-averaged fEMG recordings of all four shoulder muscles: TBLH, BB, SP, and IF for the 1st jump pre-transition strides (stride-1), transition strides (stride_0) and post-transition strides (stride_1) and the 2nd jump pre-transition strides (also stride_1), transition strides (stride_5) and post-transition strides (stride_6) during the jumping task for a representative dog. The still frame images at the top of the figure provide a visual snapshot of each stride in the series for the jumping task. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. When no shaded line appears, it indicates that there was only one performance trial available for this stride event. ST = Stance Time and SW = Swing Time.

3. Ensemble-averaged fEMG recordings of all four shoulder muscles: TBLH, BB, SP, and IF for the pre-transition strides (stride-1), transition strides (stride_0) and post-transition strides (stride_1) during the Ascending A-frame – High Apex height task for a representative dog. The still frame images at the top of the figure provide a visual snapshot of each stride in the series for the ascending A-frame task. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. ST = Stance Time and SW = Swing Time.

4. Ensemble-averaged fEMG recordings of all four shoulder muscles: TBLH, BB, SP, and IF for the pre-transition strides (stride-1), transition strides (stride_0) and post-transition strides (stride_1) during the Ascending A-frame – Low apex height task for a representative dog. The still frame images at the top of the figure provide a visual snapshot of each stride in the series for the ascending A-frame task. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. ST = Stance Time and SW = Swing Time.

5. Ensemble-averaged fEMG recordings of all four shoulder muscles: TBLH, BB, SP, and IF for the pre-transition strides (stride-1), transition strides (stride_0) and post-transition strides (stride_1) during the Descending A-frame – High apex height task for a representative dog. The still frame images at the top of the figure provide a visual snapshot of each stride in the series for the descending A-frame task. The solid line represents the mean activation across
the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. ST = Stance Time and SW = Swing Time.

6. Ensemble-averaged fEMG recordings of all four shoulder muscles: TBLH, BB, SP, and IF for the pre-transition strides (stride-1), transition strides (stride_0) and post-transition strides (stride_1) during the Descending A-frame – Low apex height task for a representative dog. The still frame images at the top of the figure provide a visual snapshot of each stride in the series for the ascending A-frame task. The solid line represents the mean activation across the sampling window and the shaded area represents +/- 1 SD across the trials for the given dog’s performance. ST = Stance Time and SW = Swing Time.

7. Interaction plots for the comparison of the average Peak EMG amplitudes for each of the agility specific tasks (d_high, d_low, j_Na, u_high, u_low) by stride event type (pre-transition stride, stride-1; transition stride, stride_0; and post-transition stride, stride_1) for all four muscles: A. TBLH, B. BB, C. SP, D. IF.

8. Interaction plots for the comparison of the average Peak EMG amplitudes for the jumping task (transition strides for jump 1: stride_0 and for jump 2: stride_5) based on the number of pre-strides taken before each jump (i.e., zero, one or two strides taken before lift-off) for all four muscles: A. TBLH, B. BB, C. SP, D. IF. For Jump 1, there are zero stride data points as several dogs chose to lift off directly from a sit into the transition stride. This did not occur for the second jump, all dogs in the sample added at least one stride between landing from the first jump before taking off for the second jump.

9. Interaction plot for the comparison of the average Peak EMG amplitudes for the two Descending A-frame post-transition strides (stride_1 for d_low and d_high) by contact performance type (run and stop) for the SP muscle which was statistically significant (p=0.03).
Figure 3.
Figure 4.
Figure 5.

Pre-transition Stride (Stride_-1)

1st Transition Stride (Stride_0)

Post-transition Stride (Stride_1)

Muscle 1 (TBLH)

Muscle 2 (GB)

Muscle 3 (SP)

Muscle 4 (IF)

<table>
<thead>
<tr>
<th></th>
<th>ST</th>
<th>SW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 6.
Figure 7.
Figure 8.
CHAPTER SIX

GENERAL DISCUSSION

Dog agility is a sport in which dogs perform a sequence of obstacles, in the order indicated by their handlers and as designed by the officiating judge.\textsuperscript{1–4} This thesis confirmed and expanded on the limited existing literature\textsuperscript{5} to document the typical pattern of injuries and predictive factors for injury among dogs training and competing in agility events. Agility-related injuries affect more than 30\% of dogs participating in the sport and soft tissue strains, sprains, and contusions to the shoulder, back, phalanges, and neck are the most common types and sites of agility-related injury in dogs. In our study, 42\% injuries were attributed to interaction with three specific obstacles: bar jumps, A-frames, and dog walks (Chapter 2).\textsuperscript{6} We identified several variables that were associated with increased odds of injury for dogs participating in agility events. Previous agility-related injury, Border Collie breed, alternative therapeutic treatments such as acupuncture, massage, and chiropractic care, and fewer years of agility-related experience (< 5 years for handlers and ≤ 4 years for dogs) were significant risk factors for injury (Chapter 3).\textsuperscript{7}

Results from these two studies\textsuperscript{6,7} were used to focus our attention on quantifying the muscular activation of four shoulder muscles (BB, TBLH, SP, and IF) during jumping and ascending/descending the A-frame which were identified as being associated with a high risk of injury in the sport (Chapter 5). Before
conducting this study, we confirmed that investigations of muscle activation during highly dynamic activities were feasible through the use of non-invasive ultrasound-guided fine-wire electromyography techniques in a canine population (Chapter 4). We also established specific guidelines regarding the placement of fine-wire electrodes and data collection and electromyography normalization procedures that can be used to guide future work in this population.

Our findings from the examination of highly trained dogs completing three specific agility-related tasks indicate that jumping is an especially demanding activity for dogs in agility. Compared to ascending and descending an A-frame, jumping requires the highest level of shoulder muscle activation for all muscles of interest. We also determined that, at least in terms of the levels of muscle activation required to perform them, there was no difference between the two most common A-frame heights used in competitions, but that there were differences in muscle activation patterns for dogs that are trained to run vs. stop when descending this obstacle. Future work should build on these findings to help shed light on the mechanisms related to shoulder injuries associated with these specific agility tasks.

Dogs are typically required to perform many more jumps on any given agility course or training session, compared to completing the A-frame obstacle. Our examination of typical courses designed by judges throughout Europe and North America in 2011 revealed, that on a standard agility course, more than 65% of the obstacles performed in the sequence were jumps. Completing the A-frame obstacle represented less than 1% of the total number of obstacles within
the sequence. This greater exposure to the jumps, coupled with our finding of higher shoulder muscle activation requirements during the jumping transition stride, is troubling. Taken together, these findings suggest that dogs repeatedly experience high demand in these shoulder muscles several times in rapid succession when completing a full agility sequence; a sequence, which typically takes between 30-40 seconds for the fastest dogs to complete. However, in between the performance of individual jump obstacles, the dogs are running on the ground and may be performing different obstacles – activities that likely require lower levels of muscle activation to perform. In contrast, completing the sole A-frame obstacle in the sequence requires less overall muscular activation, compared to jumping, but the dog performs several consecutive strides at this level of activation. This occurs because the ascending and descending tasks do not occur in isolation – i.e., the dog must do both in order to complete the obstacle. Our findings suggest that the level of muscular activation needed to fully ascend and descend the A-frame is similar across each of the six to ten consecutive strides required to complete this obstacle.

The differences in the performance requirements and the muscle activation patterns observed between these two obstacles, suggest that it is likely that the exact mechanism of injury attributable to these obstacles could also be different. For example, these injuries may result from differential magnitudes of risk due to overuse vs. overload mechanisms. Future work can focus on teasing this apart by adding both kinematic and kinetic variables while recording the muscle activation patterns as dogs perform these tasks. Being able to
quantitatively evaluate when the muscles are actively shortening, lengthening or contracting at a resting length and determining whether the muscles are acting during repetitive or singular exposure to low- or high-magnitude forces can help us understand the biomechanical mechanisms associated with these shoulder injuries.\textsuperscript{10} By collecting these data, we can then apply an inverse dynamic approach to build a linked-segment model\textsuperscript{11} of the forelimb to calculate net shoulder joint and muscle moments to examine the musculotendon dynamics in these shoulder muscles during these specific agility tasks.

One limitation to the current work, in which we normalized muscle activation levels to a submaximal dynamic task, is that it is difficult to identify at what percentage of the maximal capacity the muscles were working during these agility-specific tasks. Adding ground reaction forces to the data collection protocols of future studies could provide additional complementary information. Attention could also be given to the differences in peak activation levels between stance and swing phases in relation to the timing of eccentric and concentric contractions of these muscles. These analyses would be especially helpful in refining our understanding of the nature of the biarticular muscles acting at the shoulder joint during these highly dynamic tasks.\textsuperscript{12,13} For example, peak activations for the both the BB and TBLH were found in swing during the jumping transition stride. Functionally, the shoulder is extending and the elbow is first flexing to clear the jump and then extending to prepare for landing during this stride. This requires the TBLH and BB to be active during both stretch and shortening cycles of the muscle. This would further our understanding of the
specific etiologies of injuries related to jumping and climbing the A-frame in agility, and help identify which shoulder muscles are at a greater risk for injury within the sport.

It would be beneficial for injury surveillance systems to be introduced across jurisdictions to prospectively record injury cases. Steps could be taken to establish more precise descriptions of injury etiologies than those identified in our retrospective survey. However, we recognize that this will be difficult to achieve, for at least two reasons. First, our previous work has identified that handlers are often unaware of the circumstances that led to their dog’s injury. Nearly 30% of reported injuries in our first study were attributed to an ‘unknown’ cause. Second, since the dog can not self-report, it therefore is not possible to determine the precise moment of injury through these surveillance records. However, even with their limitations, these systems could monitor changes over time and across jurisdictions related to changes made to equipment specifications and rules adopted by the sanctioning organizations.\textsuperscript{14,15}

The findings from this work indicate that both inexperience and previous injury are significant predictors of future injury in the sport. These findings are not surprising, as studies consistently show these to be risk factors for injury in many human\textsuperscript{16–19} and equestrian sports,\textsuperscript{20–24} and in workplace\textsuperscript{25} and automobile accidents.\textsuperscript{26} We also found that Border Collies were particularly susceptible to injury, more so than other breeds participating in the sport. The exact reason for this higher risk for injury is unknown. Speculations have been made that it may be related to greater exposure, as Border Collies are known to continue working
at a higher intensity and for a longer duration than most other breeds. They were originally bred to herd stock, which requires great athletic prowess and stamina.²⁷ It could also be due to their conformation. Border Collies have greater shoulder angulation²⁷,²⁸ compared to other breeds because they were required to change directions quickly and frequently in order to perform their work on the farm.²⁷ Perhaps their heightened shoulder mobility increases their risk for injury. Border Collies also are known for their drive, speed, and quickness compared to other breeds.²⁷ The speed at which dogs execute their performance on an agility course could also be related to the increased risk of injury for Border Collies. Results from these competitions consistently document that the fastest dogs in the competition are Border Collies. Studies examining equine steeplechase, hurdle, and flat races have demonstrated that high rates of speed are associated with increased risk of injuries to the horses.²⁹–³¹ Future studies focused on examining these factors in Border Collie populations is warranted.

The results of this thesis have important implications to guide future research and prevention initiatives aimed at reducing agility-related injuries in dogs. Measures should be taken to educate handlers, coaches, judges, and sanctioning organizations about the risks for injury in the sport. This effort should target handlers that are new to the sport or working with inexperienced dogs and those that work with Border Collies, given the higher odds of injury associated with these factors.

Note: data were not presented for every stride required to complete this full obstacle. On average, the dog took four strides to complete the ascending task and three to six strides to
complete the descending task depending on whether the dog had been trained to run vs. stop at the end of the A-frame.
REFERENCES


APPENDIX ONE

AGILITY INJURY E-SURVEY

The following document represents a printed copy of the online e-survey that was administered and described in chapters two and three in this thesis.

Skip logic was present in the online survey that may have resulted in some questions shown below not being presented to the respondent based on their answer to a previous question.

Handlers were given the opportunity to report information for up to ten (10) dogs that they had competed with in the sport and up to five (5) injuries for each dog if necessary.
Agility Injury E-Survey

INFORMATION LETTER TO PARTICIPATE IN RESEARCH

A retrospective cohort examining the external risk factors of injury for canines participating in agility competitions.

You are asked to participate in a research study on the frequency of injuries to dogs involved in agility competitions. The study is being conducted by Ms. Kl Cullen from the Biophysics Interdepartmental Group at the University of Guelph under the supervision of Dr. JP Dickey, Dr. NM Mosey and Dr. J Thompson. Results from this research study will contribute to an improved understanding of mechanisms of injury in canine agility, and are part of Ms. Cullen’s PhD dissertation. This study is sponsored by the Ontario Veterinary College Pet Trust.

If you have any questions or concerns about the research, please feel free to contact Ms. Kim Cullen, Student Investigator at kcullen@uoguelph.ca or Dr. Jim Dickey at jdickey@uwo.ca.

PURPOSE OF THE STUDY

The purpose of this study is to describe the injuries that are occurring in dogs participating in agility events. We are interested in knowing more about what types of injuries are most common (such as muscle strain, ligament sprain etc.) and what part of the dog’s body (e.g., shoulder, feet, etc.) are most commonly involved. We are also interested in learning how the injuries occurred – such as whether or not there was a specific event that contributed to the injury (e.g., collision with handler, or specific piece of equipment on course).

We would like you to complete the survey if your dog(s) has/have had an injury playing agility. It is important to understand how “big” the problem is, which means we need to know about the injuries that are occurring within the context of understanding how many dogs play without ever having an injury.

This information will be used to guide the development of future research questions, as part of Ms. Cullen’s PhD dissertation, which focuses on examining the biomechanical risks of injury to dogs participating in agility events.

PROCEDURES

This survey will take less than 20 minutes of your time to complete. We would be happy to share the findings of this survey with you if you are interested. You will be given an opportunity to sign-up to receive a summary of the research findings before you finish the survey.

If you agree to participate in this study, you would be asked to answer some questions about you (your age and how long you have been training agility dogs, for example), and questions which focus on your dog’s participation in agility events. The survey will collect information on any injuries your dog has sustained while participating in agility (either in training or competition). You will have the opportunity to enter information separately for each dog in your household that has participated in agility events.

You will be asked to provide your dogs’ registration numbers for the Agility Association of Canada (AAC), United States Dog Agility Association (USDAA) and/or UK Agility (UKA) - if you play in AAC, USDAA or UKA agility. We will use these ID numbers to retrieve additional data about the number of trials you and your dog regularly attend. We will be collecting the following information from your dog’s record: owner’s name, dog name, dog breed, trial date, events entered at the trial, which events received qualifying scores, host club, and judge. This information will help us to estimate injury rates for dog agility events.

POTENTIAL RISKS AND DISCOMFORTS

The survey will ask you to reflect on any past injuries your dog may have sustained while participating in agility events. While this may remind you of a potentially distressing event, the risks involved in completing this survey are no more than would be encountered in everyday life.
POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY

You will not benefit directly from participation in this study. We will share the summary of the results with you, which may help in devising training regimes, based on the injuries that commonly occur to dogs participating in agility which can result in improved treatments for these injuries, as well as improved equipment safety standards to reduce the future risk of injury to dogs participating in agility.

PAYMENT FOR PARTICIPATION

You will not be compensated for your participation in this research study.

CONFIDENTIALITY

Every effort will be made to ensure confidentiality of any identifying information that is obtained in connection with this study.

No information that discloses your identity will be released or published. All completed data will be downloaded into a secured web server and will only be viewed by the researcher. Participant responses will be evaluated and presented collectively, rather than individually. The data will be kept indefinitely, but it will only be used for the purposes indicated above.

PARTICIPATION AND WITHDRAWAL

You can choose whether to participate in this study or not. If you volunteer to participate in this study, then you may withdraw at any time without consequences of any kind. If you choose to withdraw from the study then your data will be deleted. You may also refuse to answer any questions you don’t want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise that warrant doing so.

RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any time and discontinue participation without penalty. You may do so by simply closing your web browser window. You are not waiving any legal claims, rights or remedies because of your participation in this research study. This study has been reviewed and received ethics clearance through the University of Guelph Research Ethics Board. If you have questions regarding your rights as a research participant, contact:

Research Ethics Coordinator Telephone: (519) 824-4120, ext. 56606
University of Guelph Email: sauld@guelph.ca
437 University Centre Fax: (519) 821-5236
Guelph, ON N1G 2W1

If you would like to keep a copy of this information letter, please feel free to print this page using your web browser’s print menu.

By entering the survey, I indicate that I have read the information provided and agree to participate. If you are ready to begin the survey, please click on the link below.

I agree to participate in the agility injury e-survey.

○ Yes
○ No
Participant E-Survey

A retrospective cohort examining the external risk factors of injury for canines participating in agility competitions.

PART 1: INFORMATION ABOUT YOU AND YOUR EXPERIENCE WITH AGILITY

Please indicate your (i.e., handler’s) gender:

☐ Male  ☐ Female

Please select your (i.e., handler’s) appropriate age category below:

☐ 14 and under  ☐ 20 to 29  ☐ 60 to 69
☐ 15 to 19  ☐ 30 to 39  ☐ 70 and over
☐ 20 to 29  ☐ 40 to 49

Please tell us more about where you live. This will help us to understand if there are specific regional differences in injury patterns.

Where do I live:  

Canada  International

Other International (please specify) [ ]

Please indicate the number of dogs that you have competed with in agility (at any time over your agility career):

☐ 1  ☐ 5  ☐ 9
☐ 2  ☐ 6  ☐ 10 or more
☐ 3  ☐ 7
☐ 4  ☐ 8

Please indicate how many years of experience you have in agility (i.e., since you started training your first agility dog):

☐ 1 to 2  ☐ 7 to 8  ☐ 13 to 14
☐ 3 to 4  ☐ 9 to 10  ☐ 15 or more
☐ 5 to 6  ☐ 11 to 12

On average, how many agility trials have you participated in over the past year? (select the best response):

☐ 1 or more events per week  ☐ 1 or more event every 3 months
☐ 2 or more events per month  ☐ 1 event every six months
☐ 1 event per month
☐ Other (please specify) [ ]
On average, how many times would you say that you practice agility (either formally - in a class setting, or informally - backyard training) with your dogs (select the best response):

- More than 5 times per week
- 4 to 5 times per week
- 2 to 3 times per week
- Other (please specify)

Do you engage in any of the following preventative measures to help keep your dog ready for agility (select all that apply)?

- Pre-event warm-up
- Post-event cool-down
- Aerobic conditioning (e.g., swimming)
- Strengthening conditioning (e.g., retrieving)
- Proprioceptive conditioning (e.g., balance training)
- Other (please specify)

Do you and your dog(s) regularly participate in other canine sports?

- Yes
- No
Please indicate what other dog sports you and your dog(s) have participated in (select all that apply):

- Flyball
- Obedience
- Conformation
- Tracking
- Herding
- Rally-Obedience
- Field trials/hunt tests
- Other (please specify)
### Dog 1 Demographics

**PART 2: DEMOGRAPHIC INFORMATION FOR YOUR DOG(S)**

Note: We would like to learn more information about each of your dogs that have participated in agility (either in training or competition).

If you have more than one dog - please start by filling out these questions with your first dog in mind. You will be given the opportunity to enter this information again for your next dog(s) (up to a maximum of 10 dogs).

**Please tell us a bit of background information about your first dog:**

**Dog's name:**

**Dog's breed:**

**Please enter the following information (using decimal numbers only):**

**Dog's height at the withers (in inches):**

**Dog's average weight (in lbs.):**

**When is your dog's date of birth? Please enter in Day/Month/Year format.**

**DOB:**

**Please indicate how long your dog has been participating in agility (i.e., in years; using numbers only):**

**Please indicate which agility venues your dog has participated in:**

- [ ] Agility Association of Canada (AAC)
- [ ] United States Dog Agility Association (USDA)
- [ ] North American Dog Agility Council (NADAC)
- [ ] Canadian Kennel Club (CKC)
- [ ] American Kennel Club (AKC)

Other (please specify):

**If your dog has participated in AAC, USDA, or UK agility, please fill in your dog's registration ID number.**

- Agility Association of Canada (AAC)
- United Kingdom Agility (UKA)
- United States Dog Agility Association (USDA)

**Has this dog ever sustained an injury while participating in an agility event (training or competition)?**

- [ ] Yes
- [ ] No

**Please indicate the number of injuries your dog has sustained when competing in or practicing for agility? (Enter 0 if your dog has never had an agility-related injury).**

**# of injuries:**
**Dog 1 - Injury 1 Data**

We would like to learn more about each of the injuries your first dog has sustained while participating in agility (either in training or competition).

If your dog has had more than one injury - please start by filling out these questions with the first injury in mind. You will be given the opportunity to enter this information for up to a maximum of 5 injuries for this dog.

If your dog has suffered from a chronically recurring injury that is most likely to be an aggravation of the 'same' injury multiple times, please enter the information as if it was 1 injury and provide details on the chronic, repetitive nature of the injury in the text boxes provided.

**Did this injury occur in:**
- [ ] Practice?
- [ ] Competition?
- Other (please specify):

To the best of your recollection, please enter the date of this injury. Please enter in Day/Month/Year format.

Date (DD/MM/YYYY): __/__/____

**Looking at the figure to the right for reference, please select the body part(s) injured?**

- [ ] Head
- [ ] Neck
- [ ] Rib cage (chest)
- [ ] Flank
- [ ] Back
- [ ] Loin
- [ ] Croup
- [ ] Shoulder
- [ ] Upper arm
- [ ] Elbow
- [ ] Forearm
- [ ] Carpal joint (wrist)
- [ ] Metacarpals (front pastern)
- [ ] Front Phalanges (toe bones)
- [ ] Upper thigh
- [ ] Stifle (knee)
- [ ] Patella (knee cap)
- [ ] Lower thigh
- [ ] Tarsal joint (hock)
- [ ] Metatarsals (rear pastern)
- [ ] Rear Phalanges (toe bones)
- [ ] Footpads
- [ ] Head
- [ ] Tooth/Mouth
- [ ] Eye
- [ ] Tail
What was the nature of injury?

- [ ] Sprain (ligament injury)
- [ ] Strain (muscle/tendon injury)
- [x] Contusion (Bruise)
- [ ] Abrasion (Scrape)
- [ ] Puncture
- [ ] Fracture
- [ ] Laceration (cut)
- [ ] Other (please specify)
How did this injury occur? (i.e., did it occur from a collision with obstacle or handler, environmental conditions, etc)

- Bar Jump
- Spread jump
- Broad (Long) jump
- Panel jump
- Tire (Tyre) jump
- Dogwalk
- A-frame
- Teeter (Seesaw)

Other (please specify)

Please provide any additional information about how the injury occurred that you would like to share with us.

How long did recovery from injury take?

- Less than 1 day
- 1-2 days
- 1-2 weeks
- Less than 1 month
- 2-3 months

Other (please specify)

Did you seek medical/therapeutic intervention for your dog as a result of this injury?

- Visit to your veterinarian
- Physiotherapy
- Chiropractic treatment
- Acupuncture
- No medical/therapeutic intervention was necessary

Other (please specify)

Has this dog sustained another injury from participating in agility?

- Yes
- No
### Dog 2 - Introduction

**Do you have a second dog that has played agility?**

- [ ] Yes
- [ ] No
Thank you!

Thank you for your participation in this study.

The information you have provided regarding your agility participation is extremely valuable.

This project represents an important first step in building knowledge about common injuries occurring to dogs participating in agility which may lead to improved treatments for these injuries, as well as improved equipment safety standards to reduce the future risk of injury to dogs participating in agility.

If you would like us to forward you a summary of the findings from this research, please fill out the following information below.

Name: 

Email Address: 