Movement Patterns and Injury Incidence in Cross-Country Skiers: A Prospective Cohort Study

Sonya G. Anderson Worth

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Faculty of Health and Environmental Sciences

School of Clinical Sciences

Abstract

Purpose of the Work

This 12-month prospective study describes the characteristics of a group of elite cross-country skiers using subject demographics; intake physical measurements (Movement Competency Screen—MCS, hamstring length, and trunk muscle endurance); and monthly injury, training, and racing reports. The primary hypothesis is that new injury is associated with poor movement competency. Secondary hypotheses are that new injury is associated with (a) a history of injury, (b) a long career in cross-country skiing, (c) high training hours, (d) high running training hours, (e) high roller ski training hours, (f) poor trunk muscle endurance, and (g) reduced active straight leg raise (ASLR). Mean injury incidence will be used to examine differences between the injury incidence rates of (a) the ski season and off-season, (b) traumatic and nontraumatic injuries, and (c) injuries by anatomic location.

Introduction

Cross-country ski injury incidence studies have employed variable methodologies, using retrospective injury and training surveillance. Standardised injury incidence measures will improve the understanding of cross-country ski injury incidence. Studying the relationship between movement patterns and new injury may identify risk factors for future injury, and eventually reduce injury rates with appropriate intervention strategies.

Methods

At enrolment, 71 professional or collegiate cross-country skiers (35 men, 36 women) provided demographics and injury history, then performed the Movement Competency Screen (MCS), hamstring length, and trunk muscle endurance tests. Self-report electronic injury and training surveillance occurred monthly for 12 months. Spearman’s correlation determined the relationship between new injury and MCS score, past injury, total training time, and run training time. A *t*-test compared injury incidence (the mean number of injuries per subject per 1,000 training/exposure hours) between anatomic regions, type of injuries, and seasons.

Results/Main Points

The study was completed by 58% of subjects (18 men, 23 women). There were 3.18 injuries per subject per 1,000 training/exposure hours. New injury was not correlated with MCS score, but was correlated with previous injury ($p < .05$). New injury did increase as the time spent running increased, although not significantly ($p = .08$). New injury was not correlated with any other variable.

Risk factor analysis found previous injury was a significant predictor of new injury when accounting for overall training time, run time, and MCS score.

Lower-extremity injury incidence (2.13) was significantly higher than upper extremity (0.46) or trunk injury incidence (0.22). Nontraumatic/overuse injury incidence (2.76) was significantly higher than acute injury incidence (1.05) ($p < .05$). Off-season injury incidence (5.25) was higher than ski season (2.27), although not significantly ($p = .07$).

Conclusion

This is the first examination of the relationship between MCS score and new injury in cross-country skiers. New injury positively correlated with previous injury, but not with MCS score, hamstring length, trunk endurance ratio, or training/exposure hours. Lower-extremity and nontraumatic/overuse injuries had the highest incidence rates. Previously injured skiers are at greater risk for further injury. The results lay the foundation for further movement and injury studies and future injury prevention strategies.

Keywords: Movement Competency Screen (MCS), cross-country skiing, injury incidence

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List of Abbreviations

Abbreviation	Definition
<	Less than
=	Equal to
>	Greater than
AAA	Athletic Ability Assessment
ACL	Anterior Cruciate Ligament
ASLR	Active Straight Leg Raise
BMI	Body Mass Index
CI	Confidence Interval
FIS	International Ski Federation
FMS	Functional Movement Screen
HPSNZ	High Performance Sport New Zealand
ICC	Intra-class correlation
IOC	International Olympic Committee
kg	Kilogram
L	Left
LBP	Low back pain
LE	Lower extremity
MCS	Movement Competency Screen
NCAA	National Collegiate Athletic Association
PRT	Physical Readiness Test
R	Right
REDCap	Research Electronic Data Capture
ROM	Range of motion
SD	Standard deviation

SEBT	Star Excursion Balance Test
SI joint	Sacroiliac joint
SIC	Subsequent Injury Categorisation
UE	Upper extremity
USA	United States of America
UVM	University of Vermont
VAS	Visual Analogue Scale

Attestation of Authorship

"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the Acknowledgments), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Signed:

Date: 26 October 2016

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Ethics Approvals

The Auckland University of Technology Ethics Committee (AUTEC) granted ethical approval for this research on 4 September 2014. AUTEC Reference Number: 14/268 Nordic skiers' movement patterns and injury incidence. (Appendix 7.1).

The University of Vermont (UVM) Research Protections Office granted ethical approval for this research on 1 August 2014. UVM reference number: 14-554 Nordic Skiers' Movement Patterns and Injury Incidence (Appendix 7.2).

The Middlebury College Institutional Review Board granted ethical approval for this research on 7 October 2014. Middlebury College IRB reference number: 14551 Nordic Skiers' Movement Patterns and Injury Incidence. (Appendix 7.3).

The Bowdoin College Institutional Review Board granted ethical approval for this research on 17 November 2014. Bowdoin College IRB reference number: 2014-36 Nordic Skiers' Movement Patterns and Injury Incidence. (Appendix 7.4).

1 Introduction

1.1 Statement of the Problem

Cross-country skiing is a recreational and competitive sport practiced in regions of North America and Europe where snow covers the ground during winter months (Alricsson & Werner, 2004; Boyle, Johnson, & Pope, 1981; Orava, Jaroma, & Hulkko, 1985; Renstrom & Johnson, 1989; Ueland Ø & B, 1998). The physical and aerobic attributes of high-performance cross-country skiers are significant and are comparable to other high-performance endurance athletes (Renstrom & Johnson, 1989; Sandbakk & Holmberg, 2013). Like all endurance athletes, a cross-country skier strives to cover a greater distance in a shorter time than their competitors, and to do so over many competitive seasons. Thus, a body free from injury or illness is an important component of a long and successful career. The population of interest in this project is the competitive cross-country skier; however, the recreational cross-country skier strives for a similarly long career of many years enjoying the winter outdoors to the maximum of their ability without limitation by injury or illness, and they may benefit from the findings of this project.

The desire to excel in any sporting performance is dependent on optimal health and wellness of the athlete throughout training and competition. To achieve optimum health, and to remain injury free, one must understand the extent of any injury problem, and any effective strategies to prevent injuries from occurring (Finch & Cook, 2013; van Mechelen, Hlobil, & Kemper, 1992). The methodological variations currently used to report injuries and training/exposure in cross-country ski studies means the extent of the injury problem in cross-country skiers is not clear. To date, injury and training reporting has primarily varied between one-time retrospective 12-month surveys (Bahr et al., 2004; Blut, Santer, Carrabre, & Manfredini, 2010; Foss, Holme, & Bahr, 2012;

Østerås, Garnæs, & Augestad, 2013; Ristolainen, Kettunen, Waller, Heinonen, & Kujala, 2014), and one-time retrospective 12-month in-person interviews (Flørenes, Nordsletten, Heir, & Bahr, 2012), both of which may be affected by recall error. Medical records have been used to improve injury recording (Ueland Ø & B, 1998), and coach interviews have been used to improve training volume records (Alricsson & Werner, 2005; Alricsson & Werner, 2006; Bergstrom, Brandseth, Fretheim, Tvilde, & Ekeland, 2004). An increase in frequency of recording should reduce recall error and has been used in a 13-week prospective study (Clarsen et al., 2014). Consistent injury incidence calculation is dependent on consistent recording of injury type, injury mechanism, and training load. A broad range of cross-country ski studies must employ consistent recording of injury and training to provide robust data for future injury prevention strategy studies, which may in turn offer the opportunity to prevent injuries (Finch & Cook, 2013; van Mechelen et al., 1992). The use of a monthly injury and training survey for 12 consecutive months will reduce recall bias and improve accuracy of injury and training reporting.

Injuries to the lower extremities (Flørenes et al., 2012; Østerås et al., 2013; Ristolainen et al., 2014) and low back (Alricsson & Werner, 2005; Alricsson & Werner, 2006; Bahr et al., 2004; Blut et al., 2010; Flørenes et al., 2012; Foss et al., 2012) are consistently reported by high-level cross-country skiers. Reported injury rates are variable depending on the reporting method and the study reviewed. Only one investigator (Ristolainen et al., 2010) has thus far reported injury incidence for cross-country skiers (2.08 injuries per 1,000 exposure hours in elite cross-country skiers). All other authors have preferred to report the more-difficult-to-compare injury frequency or prevalence. Prevalence of lower-extremity injuries in cross-country skiers ranges from 20% (Clarsen et al., 2014) to 56% (Østerås et al., 2013). Prevalence of low back pain in cross-country skiers ranges from as low as 5% (Clarsen et al., 2014) to 25% (Flørenes et al., 2012), to as high as 63% (Bahr et al., 2004).

Previous injury (Ristolainen et al., 2014), periods of high-volume training within a season (Bahr et al., 2004), year-long training volumes greater than 700 hours per year (Ristolainen et al., 2014), and less than two days' rest during the off-season (Ristolainen et al., 2014) are the currently identified risk factors for elevated injury rates in cross-country skiers. Continued investigation of intrinsic and extrinsic risk factors for injury in cross-country skiers is warranted to improve the understanding of injury risk in cross-country skiers.

Whole body movement screening has become popular as part of the preparticipation medical screening in competitive sports, as the sports medicine teams strive to maximise each athlete's physical performance and minimise the number of performance-limiting injuries (Cook, Burton, & Hoogenboom, 2006a, 2006b; Cook, Burton, Hoogenboom, & Voight, 2014a, 2014b; Kiesel, Plisky, & Voight, 2007). Whole body movement screens (such as the Functional Movement Screen, the Movement Competency Screen, and the Athletic Ability Assessment) aim to identify and describe movement competency and, by observing movement impairments, use the results of the screen to determine whether the individual's movement requires further, more detailed investigation (Cook et al., 2014b). That is, movement competency, not injury prediction, was the aim of the developers of these whole body movement assessment screens.

The Functional Movement Screen (FMS) is a whole body movement screen that has been shown to be a reliable tool to evaluate whole body movement in a variety of populations including: military and police populations (Bock, Stierli, Hinton, & Orr, 2016; O'Connor, Deuster, Davis, Pappas, & Knapik, 2011), athletic populations (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Hall, 2014; Kiesel, Butler, & Plisky, 2014; McGill, Andersen, & Horne, 2012; Wiese, Boone, Mattacola, McKeon, &

Uhl, 2014), and a generally young active population without specific sports affiliations (Schneiders, Davidsson, Hörman, & Sullivan, 2011). A low FMS score (<14/21) has been correlated with elevated injury risk in NCAA American football players (Kiesel et al., 2014), USA marine officer candidates (O'Connor et al., 2011), and female NCAA soccer, volleyball, and basketball players (Chorba et al., 2010). However, the FMS has, conversely, not been positively correlated with elevated injury risk in NCAA American football players (Hall, 2014; Wiese et al., 2014) or in NCAA athletes from basketball, American football, volleyball, cross-country running, track and field, swimming/diving, soccer, golf, and tennis (Warren, Smith, & Chimera, 2015). The disagreement about correlation of FMS score with injury risk supports the call for ongoing study of injury risk factors, perhaps with a multifactorial injury risk focus rather than movement competency alone.

The Movement Competency Screen (MCS) is a whole body movement screen that has been shown to be a reliable tool to evaluate whole body movement in a variety of active populations: military recruits (Milbank, Peterson, & Henry, 2016), dancers (Lee, 2015), netball players (Reid, Vanweerd, Larmer, & Kingstone, 2015), and rowers (Newlands, 2013). A low MCS score (<23/36) has been correlated with elevated injury risk in high-performance dancers (Lee, 2015), but not in rowers (Newlands, 2013) or military recruits (Milbank et al., 2016). As with the FMS score, the disagreement about correlation of MCS score with injury risk supports the call for further study of the MCS in active populations, perhaps with a multifactorial injury risk focus rather than movement competency alone.

No reports were found of any whole body movement screen being used as a means to define movement competency and further detect cross-country skiers at risk for future injury. Investigating the relationship between whole body movement competency and injury data may enable identification of additional risk factors for injury in cross-country skiers, which would in turn provide data for further study into the prevention of injury in cross-country skiers. The current challenges regarding correlation of movement screen scores with injury risk in other sports do prompt consideration that there may be intrinsic or extrinsic factors, in addition to movement competency, involved in injury risk for cross-country skiers.

Prior to the popularisation of whole body movement screening, physical screening of athletes involved impairment level tests of muscle length and strength, and joint range of motion. Deficits in hamstring muscle length and trunk muscle endurance have been correlated with low back pain (Biering-Sorensen, 1984; Latimer, Maher, Refshauge, & Colaco, 1999). Impaired spine and hip joint range of motion have been hypothesised, but not proven, to increase the risk of low back pain in cross-country skiers (Alricsson & Werner, 2004). Investigating the relationship between injury and impairment level muscular measures such as hamstring length and trunk muscle endurance in cross-country skiers will contribute to baseline movement pattern data in cross-country skiers.

1.2 Purpose of the Study

The purpose of this study was to examine the relationship between MCS score and new injuries in a group of NCAA and professional cross-country skiers to determine the effect of movement competence (assessed by the MCS) on the occurrence of new injuries.

To achieve this purpose, a 12-month prospective study of elite and recreational cross-country skiers will be undertaken. The study will collect injury history, baseline MCS scor, hamstring length (hip flexion range of motion, ROM, measured from the active straight leg raise, ASLR, test), trunk flexor muscle endurance time (recorded from the McGill trunk flexor muscle endurance test), trunk extensor muscle endurance time (recorded from the Biering-Sorenson trunk extensor muscle endurance test), monthly injury reports, monthly training, and monthly racing data (from self-report monthly surveys). The following hypotheses will then be tested to accomplish the purpose of the study.

The primary hypothesis of this study is that new injury is associated with poor movement competency (assessed by the MCS score) in cross-country skiers. The secondary hypotheses are that new injury is associated with (a) a history of injury, (b) a long career in cross-country skiing, (c) high training hours, (d) a high number of training hours spent running, (e) a high number of training hours spent roller skiing, (f) poor trunk muscle endurance ratio (using the ratio of trunk flexor to trunk extensor endurance time recorded from the McGill trunk flexor muscle endurance test and the Biering-Sorenson trunk extensor muscle endurance test), and (g) reduced ASLR (where reduced hip flexion ROM indicates short hamstring muscles).

In addition, this study aims to describe the characteristics of a group of NCAA and professional cross-country skiers in the northeastern USA using subject demographics; intake physical measurements (MCS, hamstring length, and trunk muscle endurance ratio); and monthly injury, training, and racing reports from 12 consecutive monthly surveys. From these data, we will report mean injury incidence per subject, per 1,000 hours of training/exposure. Once injury incidence is calculated, we will determine if injury incidence is different between (a) the ski season and off-season, (b) traumatic and nontraumatic injuries, and (c) injuries by anatomic location.

The MCS scores, hamstring length, and trunk muscle endurance ratio, along with the injury type and injury incidence per 1,000 exposure hours for cross-country skiers, will contribute to the body of knowledge about cross-country skier movement patterns and injuries, and they will provide baseline data for further movement and injury studies and future injury prevention strategy research.

1.3 Significance of the Problem

Injury prevention is an important focus of sports medicine practitioners and researchers. This study will examine the relationships between new injury and the MCS score, hamstring length, trunk muscle endurance ratio, and training load over 12 months in high-level cross-country skiers in northeastern America. Cross-country ski training and injury data currently reported in the literature have been collected retrospectively using one-time recall of the previous 12 months. This will be the first study to collect cross-country ski training and injury data on a monthly frequency for 12 months, which will improve accuracy of injury and training data. There is currently no whole body movement screen data for cross-country skiers. This will be the first study to report MCS scores for competitive cross-country skiers, and also the first study to examine the relationship between new injury and any whole body movement screen in cross-country skiers. The movement screening outcomes, training, and injury profiles of cross-country skiers from this study will be of interest to all members of the sports medicine teams who manage injury prevention, injury rehabilitation, training, and competition scheduling for competitive cross-country skiers and other endurance sports. The data will also provide a springboard for future injury reduction and injury prevention studies in cross-country skiers.

2 Review of Literature

This review of literature is divided into nine sections. The first section is a brief overview of the development of competitive cross-country skiing, to provide an understanding of the sport to be studied. The second section reviews the current framework for injury prevention research, outlining the necessary steps for researching injury prevention. The third section is a review of cross-country ski injuries. The cross-country ski injury section covers injuries by anatomic location, injuries by severity (time lost to injury), and injuries by acuity (acute traumatic or chronic overuse). The fourth section explores what is known about risk factors for injuries in cross-country skiing. Given that whole body movement screening may be a useful component of athlete assessment for determining injury risk, the fifth section reviews movement screening tests in sports medicine. The sixth section reviews whole body movement screening tools used in active populations, as well as the injury prediction abilities of these tools. The chapter concludes with sections on justification for the use of the Movement Competency Screen (MCS) (section seven), conclusions to the literature review (section eight), and a statement of study hypotheses (section nine).

2.1 A Brief Overview of the Development of Competitive Cross-Country Skiing

Skis have been used for over 4,000 years as a means of transportation for hunting, gathering, and social connection in regions of the world where snow covers the ground during the winter months (Florenes, 2010; Renstrom & Johnson, 1989). Recreational and competitive cross-country skiing developed from this need to travel over snow-covered terrain (Florenes, 2010; Renstrom & Johnson, 1989). At ski resorts the snow surface is groomed smooth along flat and undulating trails cleared of vegetation to make way for skiers to travel; however, recreational cross-country skiing may also occur wherever snow is available (Renstrom & Johnson, 1989). The first skiing competitions were held in the 1840s in northern and central Norway, and thereafter the sport spread to Europe and the United States (Florenes, 2010). The development of competitive skiing throughout the world resulted in the establishment of the Federation International de Ski (FIS) in 1924 (IOC, 2011). The Nordic ski disciplines (cross-country skiing, ski jumping, and Nordic combined) have been on the Olympic programme for men since the first Winter Olympic Games in Chamonix in 1924 (Florenes, 2010; IOC, 2011). Women's cross-country skiing entered the Winter Olympic Games in Oslo in 1952 (IOC, 2011). With steep uphill and downhill terrain and repeated changes between techniques, cross-country skiing is technically challenging, with considerable demands on the athlete's aerobic and anaerobic power, strength, speed and endurance, and technical and tactical expertise (Holmberg, 2015).

2.1.1 Cross-country skiing competitions.

There are a variety of Olympic and International Ski Federation (FIS) races differentiated by the ski technique and distance of the course (IOC, 2011). A cross-country ski race course should consist of: one-third up hills (gradient 9–18%) with some short climbs steeper than 18%; one-third undulating, rolling terrain; and one-third varied downhills (Florenes, 2010; Sandbakk & Holmberg, 2013). Races last from three minutes to two hours, depending on the event, snow conditions, and ability of the skier (Holmberg, 2015; Sandbakk & Holmberg, 2013). Thus, cross-country skiing can be considered an aerobic activity, with all but the very short sprint races being considered endurance events (Holmberg, 2015). During short races (5–15 km), the aerobic process accounts for 95% of the total energy expenditure for men and 90% for women (Renstrom & Johnson, 1989). During longer races (30–50 km), the aerobic energy system provides up to 98% of the energy needs of the athlete (Renstrom & Johnson, 1989). The elite cross-country skier is thus characterised by extremely high maximum aerobic power (Holmberg, 2015; Renstrom & Johnson, 1989).

2.1.2 Kinematics of cross-country skiing techniques.

Cross-country skiing is a biomechanically complex sport that relies on individuals using their arms, legs, skis, and ski poles in a coordinated manner to successfully propel themselves forward across a variety of snow-covered terrain using a range of techniques according to skiing conditions, speed, and individual preference (Marsland et al., 2012; Stoggl et al., 2013). There are two major techniques: classic (diagonal) and freestyle (skating). Both of these will be explained in the following sections. Each technique has a variety of unique subtechniques that are used by skiers in a similar way to the gears a cyclist uses to navigate varied terrain (Marsland et al., 2012). Since the Winter Olympic Games in Calgary in 1988, specific cross-country ski events have been designated as classic or skate technique. Prior to 1988, skiers were required to use the classic technique exclusively for all events (IOC, 2011).

2.1.2.1 Classic technique.

In classic cross-country skiing, skis generally remain parallel and only move sideways during turning techniques (Marsland et al., 2012). Figure 2.1 shows skiers transitioning between double poling, through kick double poling, to diagonal striding.

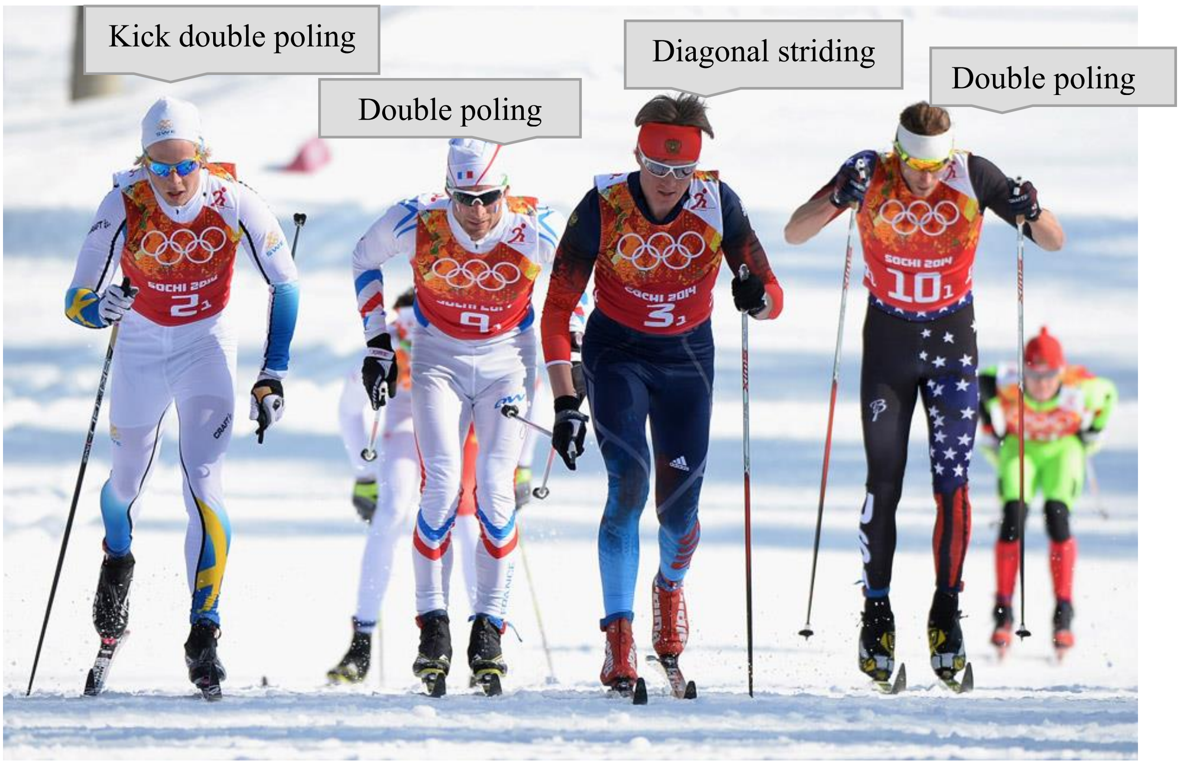

Figure 2.1. Cross-country skiing classic technique (diagonal and double pole techniques shown). Photo credit: http://www.olympic.org/cross country-skiing.

2.1.2.2 Skate technique.

In all skate movement patterns the skier pushes off from his rear ski in a motion similar to ice skating. These lateral pushes on the skis result in the skating movement (Lawson, Reid, & Wiley, 1992). Figure 2.2 shows skiers in a variety of phases of the skate skiing movement patterns.

Figure 2.2. Cross-Country Skiing Skate Technique. Photo credit: http://www.olympic.org/cross country-skiing.

2.1.3 Cross-country ski training.

To prepare their bodies for competitive cross-country skiing, participants must train for the variations in race duration, ski technique, and environmental conditions. As one of the most demanding endurance sports, cross-country skiing requires combined upper- and lower-body effort of varying intensity and duration, on hilly terrain, often at moderate altitude, and in a cold environment (Holmberg, 2015). Therefore, cross-country skiers demonstrate a very high VO_2 max, and upper and lower bodies that are nearly equally well trained (Holmberg, 2015).

With the recent introduction of shorter sprint events, the demands on anaerobic capacity, upper-body power, high-speed techniques, and “tactical flexibility” have increased (Sandbakk & Holmberg, 2013). Skiers and their coaching staff are placing greater focus on upper-body power and are more systematically performing strength training and high-speed skiing (Sandbakk & Holmberg, 2013). Even with these developments, aerobic conditioning/endurance training still constitutes 75–85% of the 800–900 training hours per year for elite European skiers (Sandbakk & Holmberg, 2013). European ski high school skiers train 485–585 hours per year (Alricsson & Werner, 2006), which is similar to American university cross-country skiers, who average 500–600 hours per year (Woods, Petron, Shultz, & Hicks-Little, 2015). Athletes training greater than 700 hours per year, or having less than two rest days per week during the off-season, have been reported to be at higher risk for injury (Ristolainen et al., 2014). As sport science continues to learn more about injury type, injury risk, and injury prevention, there will likely be further developments in the training practices of cross-country skiers as they aspire to ski faster, for longer, with fewer injuries.

2.2 Framework for Injury Prevention Research

The difficulty in preventing injury seems to be directly related to the inability to consistently determine those athletes who are predisposed to injuries (Cook et al., 2006b). The four-step sequence of injury prevention (Figure 2.3) was developed by van Mechelen et al. (1992) to formally describe the process of injury prevention research. This sequence of injury prevention has been the classic approach to sports injury prevention research over the past 25 years.

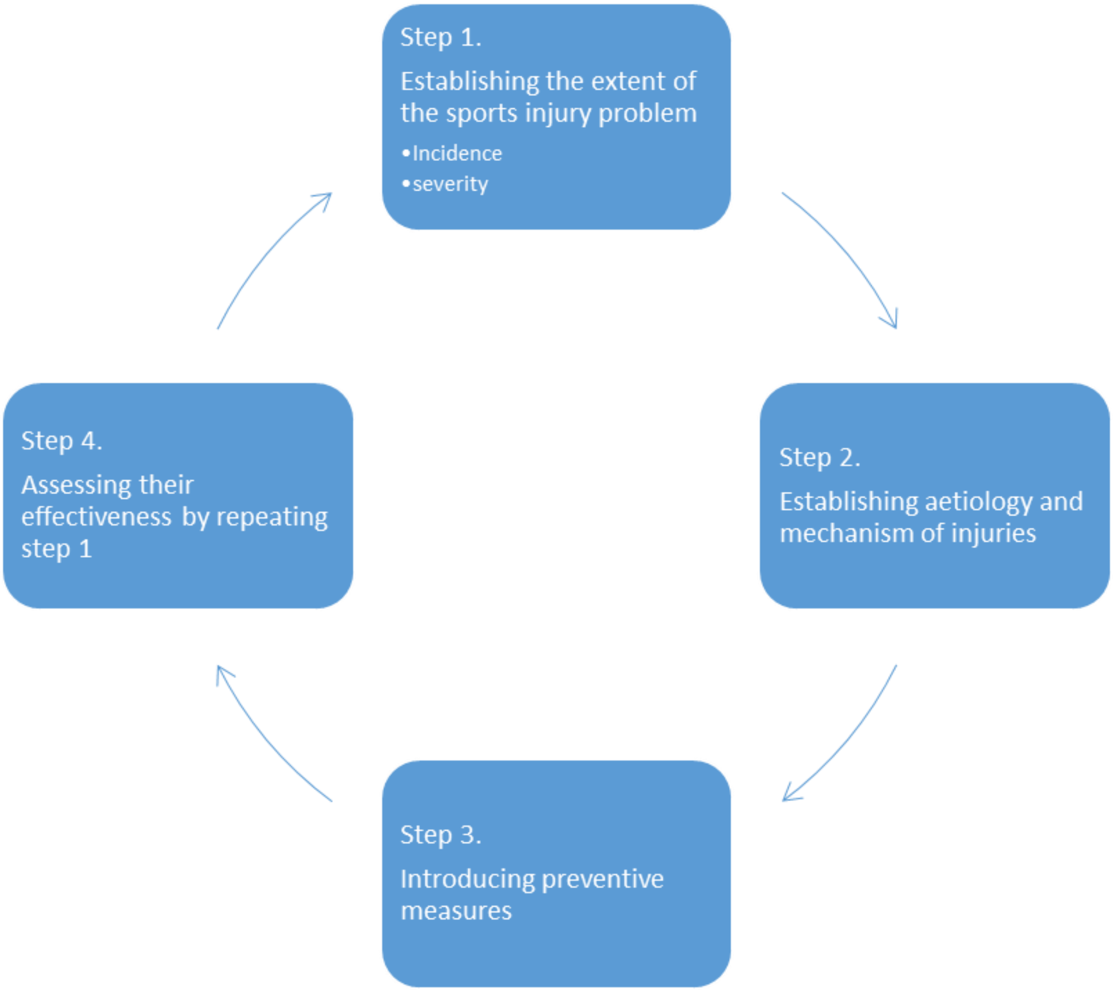

Figure 2.3. " Sequence of prevention".

As described by van Mechelen et al. (1992), to prevent injuries we first must understand who is at risk for what type of injury. Only then can the questions of what causes injuries and by what mechanisms they occur be studied. The answers to these questions enable preventive measures to be investigated. The preventive measures must then be validated by showing a reduction in the frequency of who is at risk for injury and the type of injuries sustained (van Mechelen et al., 1992).

Published cross-country ski studies have addressed step 1 and step 2 of the "sequence of prevention." Table 2.1 summarises the findings of the current literature surrounding type of injury, anatomic location, and severity of injury for cross-country skiing (step 1 of the "sequence of prevention"). Cross-country skiers report injuries to the low back, lower extremities, and less often the upper extremities (Alricsson & Werner, 2005; Alricsson & Werner, 2006; Bahr et al., 2004; Bergstrom et al., 2004; Blut et al., 2010; Butcher & Brannen, 1998; Clarsen et al., 2014; Flørenes et al., 2012; Foss et al., 2012; Lindsay, Meeuwisse, Vyse, Mooney, & Summersides, 1993; Orava et al., 1985; Østerås et al., 2013; Ristolainen et al., 2010; Ristolainen et al., 2014; Ueland Ø & B, 1998). The foot and ankle region is injured more often than other anatomic regions of the lower extremity. Step 2 of the "sequence of prevention" seeks to determine the aetiology and mechanism of injuries. Fewer published studies have addressed this step for the cross-country skier. Injuries have been reported to occur more often in activities other than skiing (Orava et al., 1985; Ristolainen et al., 2010).

While the van Mechelen et al. (1992) "sequence of prevention" is a solid framework for studying injuries, further understanding of risk factors for injury and the nature of chronic overuse injuries is also necessary (Finch & Cook, 2013). Finch and Cook (2013) developed the Subsequent Injury Categorisation (SIC) model to record acute and overuse injuries in a methodical manner, which allows detailed injury analysis (new, recurrent, exacerbation, and multiple injuries are reported and analysed). Application of the SIC model by Finch and Cook (2013) showed that athletes can sustain a number of (mostly unrelated) injuries over one competitive season, although subsequent injuries related to previous injuries are also reported. Understanding that acute new injuries have a different set of risk factors, injury mechanisms, and aetiology than chronic overuse injuries is critical to developing effective injury prevention strategies that should be tailored to the injury targeted for prevention. Given that cross-country skiers sustain more gradual onset injuries (i.e., chronic overuse injuries; Blut et al., 2010; Østerås et al., 2013; Ristolainen, Heinonen, Waller, Kujala, & Kettunen, 2009) that prevent full participation in training and racing for short periods of time (i.e., low severity; Blut et al., 2010; Clarsen et al., 2014; Flørenes et al., 2012; Ueland Ø & B, 1998), the SIC model may be more useful in the long-term study of injury in cross-country skiers. A number of different injury prevention strategies may be warranted for any given sport, team, or athlete to address the risk factors for acute and chronic overuse injuries specific to the sport (Finch & Cook, 2013).

The current study addresses step 1 of the “sequence of prevention” by identifying the extent of injuries in elite cross-country skiers and describing the types of injuries sustained. Future studies can build on this work to determine risk factors, validate risk factor predictive ability, and eventually instigate a prevention programme specific to the types and mechanisms of injuries in elite cross-country skiers.

2.3 Review of Cross-Country Ski Injuries

This review takes a narrative format but the relevant papers have been sourced in a systematic way.

2.3.1 Literature search strategy.

The 46 articles reviewed for this study were selected from an in-depth search of the following databases: OVID Medline; CINAHL and Google Scholar from 1980 to April 2015. To establish our key search words and terms, the primary investigator surveyed the current literature and discussed cross-country ski injuries with coaches and skiers. Low back pain was specifically included in the search for a number of reasons: (i) the broad interest in low back pain in the rehabilitation community, (ii) the mention of low back pain in a number of cross-country ski studies, (iii) to allow comparison of the study population with the population of elite rowers used in a previous injury incidence and movement pattern study that used comparable methodology (Newlands, 2013), and (iv) due to the focus on low back pain in the research agenda of one of the supervisors. The key search words and terms used included: low back pain; injur$; alpine ski$ or cross-country ski$.tw.; athletic injuries; athletes/elite or endurance.tw.; sports/elite or endurance.tw. Combinations of these terms were also used. In addition, reference lists of selected journal articles were hand searched to locate any additional publications relevant to this study. A web of science citation search was performed on the identified articles to find others who are referencing the articles we already found. The titles and abstracts of identified articles were reviewed for potential relevance. The full text of possibly relevant articles was then analysed before final inclusion if the article was peer reviewed; was published in English; and reported cross-country ski injuries by anatomic location, acuity (acute or overuse), severity (time loss), incidence, or prevalence. The literature was monitored between April 2015 and April 2016 for any newly published articles of relevance, and these were included as they were published. The final selection of relevant studies numbered 16.

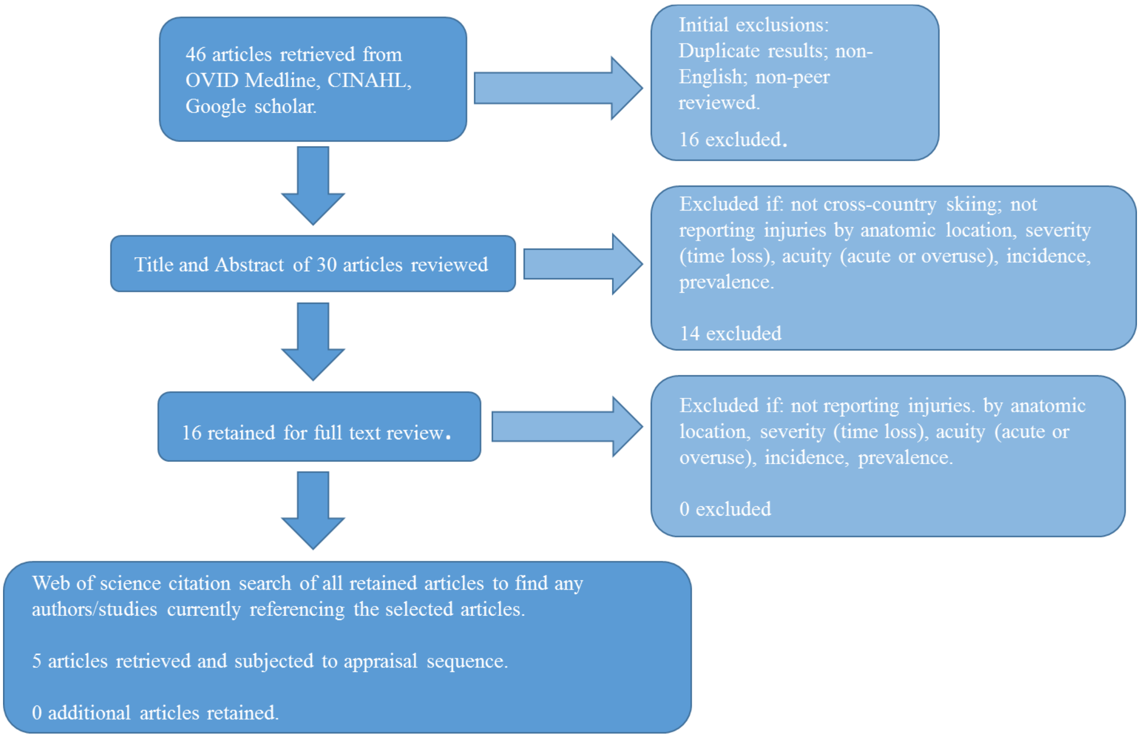

Figure 2.4. Literature search strategy.

2.3.2 Definition of injury types used in this review.

Fuller et al. (2006) published a consensus statement aiming to establish definitions and methodology, implementation, and reporting standards that should be adopted for studies of injuries in football and to provide the basis for studies of injuries in other team sports. This publication was in response to a call from the 1st World Congress on Sports Injury Prevention in Oslo in June 2005, for common methodologies and injury definitions to be used in injury studies to improve the comparability of study outcomes within and between sports (Fuller et al., 2006). Although this consensus statement focused on football (soccer) injury research, the recommended definitions and methodologies have been applied to cross-country skiing and other sports (Ristolainen et al., 2010), as was intended.

2.3.2.1 Definition of an injury.

Fuller et al. (2006) defined an injury as: “Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities” (p. 26).

2.3.2.2 Definition of injury severity.

2.3.2.2.1 Acute injuries.

An acute injury can be defined as occurring suddenly or accidentally, interrupting the exercise or the competition of the athlete, or causing an identifiable trauma. An acute injury is any physical injury that keeps the athlete away from at least one training session or competition, or requires medical care (Fuller et al., 2006; Ristolainen et al., 2010).

Acute injuries may be grouped according to their severity based on the time loss: slight (0 days), minimal (1–3 days), mild (4–7 days), moderate (8–28 days), severe (>28 days), or career ending (Fuller et al., 2006; Ristolainen et al., 2010). Ristolainen et al. (2010) combined some of these groups to define minor injury as time loss from training and competition from no time loss to 6 days, and major injury as greater than 3 weeks’ time loss from training and competition (Ristolainen et al., 2010).

2.3.2.2.2 Chronic injuries.

A chronic or overuse injury causes pain during exercise loading without any noticeable external cause of injury. A chronic injury can be defined as an overuse injury caused by repeated microtrauma without a single, identifiable event responsible for the injury (Fuller et al., 2006). The injury gradually causes worsening pain during or after exercise. Pain becomes worse when loading is continued and may eventually stop exercise completely (Ristolainen et al., 2010).

2.3.2.2.3 Traumatic injuries.

This term defines an injury resulting from a specific, identifiable event (Fuller et al., 2006).

2.3.2.2.4 Nontraumatic injuries.

These injuries occur without association with any traumatic event.

2.3.2.2.5 Time loss injuries.

These are injuries that prevent an athlete from participating in training or competition, or that an athlete requires medical care for (Ristolainen et al., 2010).

2.3.3 Types of cross-country ski injuries.

Overuse and acute traumatic injuries to the lower leg and lumbar and thoracic spines are most commonly reported in recent cross-country ski injury literature (Bahr et al., 2004; Florenes, 2010; Foss et al., 2012; Østerås et al., 2013; Ristolainen, 2012). Studies published prior to the year 2000 also report shoulder girdle overuse injuries (Orava et al., 1985; Renstrom & Johnson, 1989). Table 2.1 summarises studies that reported cross-country ski injuries by anatomic location, severity (training time lost due to injury), or acuity (acute traumatic, or chronic overuse). These categories of injury will be discussed in the following sections.

2.3.3.1 Cross-country ski injuries by anatomic location.

When all regions of the body were considered, the lower extremity was reported injured more often than the upper extremity and the trunk. Table 2.1 shows that six studies reported injuries by major body regions of lower extremity, trunk, and upper extremity. One study reported injury by body region using injury incidence (Ristolainen et al., 2010), and the remaining five studies reported injury by body region using injury prevalence (Clarsen et al., 2014; Flørenes et al., 2012; Orava et al., 1985; Østerås et al., 2013; Ueland Ø & B, 1998). Injury prevalence is a measurement of all the individuals in a group who are injured at a particular time, thus indicating how widespread injury is within that group. Injury incidence is a measurement of the number of new injuries reported during a particular time period, thus indicating the risk for developing an injury in a specified time period. The wide variation in injury reporting between these studies makes direct comparisons difficult. However, a pattern can be seen that lower-extremity injury is more prevalent than trunk or upper-extremity injury in cross-country skiers, even when reporting injury incidence (Ristolainen et al., 2010) rather than prevalence (Clarsen et al., 2014; Flørenes et al., 2012; Orava et al., 1985; Østerås et al., 2013; Ueland Ø & B, 1998), or recorded injuries from selected anatomic locations (Clarsen et al., 2014) rather than all possible body parts (Flørenes et al., 2012; Orava et al., 1985; Østerås et al., 2013; Ristolainen et al., 2010; Ueland Ø & B, 1998).

2.3.3.2 Cross-country ski injuries by severity (time lost to injury).

Slight to minimal injuries resulting in 0–3 days of impaired participation in training or racing are the most commonly reported by cross-country skiers (Blut et al., 2010; Flørenes et al., 2012). In Table 2.1, authors of seven different studies reported the time lost to injuries (Bahr et al., 2004; Blut et al., 2010; Butcher & Brannen, 1998; Clarsen et al., 2014; Flørenes et al., 2012; Østerås et al., 2013; Ueland Ø & B, 1998) but used a variety of methods, making comparisons, or even trends, difficult to ascertain. The variety of time loss was reporting included (i) intervals of weeks (Østerås et al., 2013), (ii) number of days absent (Flørenes et al., 2012), and (iii) whether training or racing was missed (Bahr et al., 2004; Butcher & Brannen, 1998). Two studies can be compared, Blut et al. (2010) and (Flørenes et al., 2012), as they did use the same injury severity classification taken from a 2006 consensus statement on injury definitions and data collection procedures in studies of football (soccer; Fuller et al., 2006). In these two studies, injury severity is defined by number of recovery days needed: slight (0 days), minimal (1–3 days), mild (4–7 days), moderate (8–28 days), and severe (>28 days). Table 2.1 shows that the distribution of injury severity is similar between the Blut et al. (2010) and (Flørenes et al., 2012) studies (>60% slight or minimal severity, <20% mild and moderate categories) even though Blut et al. (2010) used a self-report retrospective survey while Flørenes et al. (2012) used an in-person retrospective interview, and Blut et al. (2010) studied 116 elite biathletes while Flørenes et al. (2012) studied 430 cross-country skiers. It should be noted that in contrast to cross-country skiers, biathletes ski exclusively skate technique, while carrying a rifle on their backs, and intersperse their skiing with periods of standing and prone lying shooting tasks (Blut et al., 2010). Therefore, regardless of the differing physical demands of cross-country skiing compared to biathlon, as well as the differences in method of collecting injury reports, the severity of injuries is slight or minimal for cross-country skiers and biathletes.

2.3.3.3 Cross-country ski injuries by acuity (acute traumatic or chronic overuse).

In Table 2.1, it can be seen that chronic overuse injuries were reported more than acute traumatic injuries for cross-country skiers, as expected in a noncontact endurance sport. A trend of low overall injury incidence, and even lower acute traumatic injuries, in endurance athletes was seen in the two studies reporting injury by acuity (Blut et al., 2010; Ristolainen et al., 2010). Direct injury acuity comparisons cannot be made as Blut et al. (2010) reported injury prevalence (percentage of injuries) in 116 elite biathletes, while Ristolainen et al. (2010) reported injury incidence (number of injuries per 1,000 exercise hours) in 149 cross-country skiers. However, greater than half of the injuries reported by Blut et al. (2010) were of gradual onset (54%) and Ristolainen et al. (2010) reported a greater incidence of overuse injuries (1.35 overuse injuries per 1,000 exercise hours) than acute injuries (0.73 acute injuries per 1,000 exercise hours). Chronic overuse type injuries, combined with the small amounts of training and racing time lost to injury in these studies, suggests that skiers continue to train while experiencing overuse injuries. It is possible that cross-country skiers are able to modify their training activities to accommodate impairments or limitations due to overuse injuries rather than losing a training session altogether. Further analysis of data, or more explicit questioning of skiers, may yield more information about the number of skiers who train while injured and the impact of such injuries on their preparation for competition.

Table 2.1. Studies Reporting Injuries by Type (Acute or Chronic), Anatomic Location, and Severity (Time Loss)

Study reference	Study design	Participants	Results: Type of injury. Anatomic location. Severity.
Clarsen et al. (2014)	Prospective questionnaire (weekly for 13 weeks)	45 cross-country skiers 98 cyclists 50 floorball players 55 handball players 65 volleyball players	**% of injuries by anatomic location:** knee 8% (skiers), 22.8% (average of all five sports); lower back 5% (skiers), 15.2% (average of all five sports); shoulder 1% (skiers), 12.2% (average of all five sports); anterior thigh 12% (skiers), 8% (cyclists; not asked for other sports) **% of injuries by severity:** substantial overuse 10% (skiers), 14.8% (average of all five sports); all overuse 26% (skiers), 54.2% (average of all five sports)
Ristolainen et al. (2014)	12-month retrospective self-reported postal questionnaire	Elite Finnish athletes from four sports 446 men and women, 15–35 years old	**Incidence of overuse injury per 1,000 exposure hours:** skiers 1.35, swimmers 1.48, runners 1.67 **Incidence of overuse injury per 1,000 exposure hours, by anatomic location, in skiers**: back 0.42, knee 0.55, calf and shin 0.34, foot (including Achilles tendon) 0.59
Østerås et al. (2013)	Retrospective cross-sectional postal questionnaire	148 Norwegian female biathletes 118 athletes were 16–21 years (juniors), and 30 athletes were 22 years or older (seniors), mean age was 19.1 years	**% of injuries by anatomic location:** 23% knees, 12.2% calf, 10.8% ankle/foot, 10.8% lower back, 10.1% thigh **% of injuries by severity:** 23.5% knee problems lasted 1–2 weeks, 55.9% lasted >4 weeks; 72.2% calf problems lasted >4 weeks; 31.2% ankle/foot problems lasted 1–2 weeks, 37.5% lasted >4 weeks; 87.5% lower back problems lasted >4 weeks; 75% thigh problems lasted >4 weeks

Study reference	Study design	Participants	Results: Type of injury. Anatomic location. Severity.
Flørenes et al. (2012)	Retrospective in-person interviews at the end of the 2006–07 and 2007–08 winter seasons	2121 FIS World Cup snow sport athletes were interviewed	**% of injuries by anatomic location, cross-country skiers:** trunk 29.2% **(**25% lower back/pelvis/sacrum), upper extremity 31.3% (14.6% shoulder/clavicle), lower extremity 39.7% (10.4% lower leg, Achilles tendon, 10.5% lower leg ankle and foot combined) **% of injuries by severity:** 60.5% resulted in 0–3 days' absence from activity; 12.5% 4–7 days' absence; 18.8% 8–28 days' absence
Foss et al. (2012)	Prospective cohort, two retrospective 12-month surveys, 10 years apart	242 cross-country skiers 173 rowers 209 orienteers 116 control subjects Age: men 33 +/- 5 women 31 +/- 4	**% of injuries by anatomic location:** **Skiers:** 69% LBP ever, 55% LBP previous 12 months, 17% LBP previous 7 days **Rowers:** 68% LBP ever, 57% LBP previous 12 months, 19% LBP previous 7 days **Controls:** 64% LBP ever, 53% LBP previous 12 months, 20% LBP previous 7 days
Blut et al. (2010)	Retrospective 12-month survey	116 biathletes completed an online survey at a December 2008 World Cup Biathlon event 51 males, 65 females, mean age 21 years	**% of injuries by type of injury:** gradual onset 54%, sudden onset 40% **% of injuries by anatomic location:** low back 20.6%, knee 14.7%, lower leg 22.1%, shoulder 13.2% **% of injuries by severity:** 63.2% slight or minimal, 16.2% mild

Study reference	Study design	Participants	Results: Type of injury. Anatomic location. Severity.
Ristolainen et al. (2010)	Retrospective 12-month survey	149 cross-country skiers 154 swimmers 143 long-distance runners 128 soccer players Aged 15–35 years	**Incidence of overuse injury per 1,000 exercise hours, by sport:** skiers 1.35, swimmers 1.48, runners 1.67, soccer 1.69 **Incidence of acute injury per 1,000 exercise hours, by sport:** skiers 0.73, swimmers 1.1, runners 1.01, soccer 3.37 **Incidence of overuse injury per 1,000 exercise hours, by anatomic location, in skiers:** lower extremities 2.10, back 0.42, upper extremities 0.27 **Incidence of acute injury per 1,000 exercise hours, by anatomic location, in skiers:** lower extremities 1.64, back 0.44, upper extremities 0.31 49% of injured cross-country skiers had only minor injuries (<6 days lost)
Ristolainen et al. (2009)	Retrospective 12-month survey	312 females, 262 males Age 15 to 35 years; high-level cross-country skiers, swimmers, long-distance runners, and soccer players in Finland	**Incidence per 1,000 exposure hours**: **Ski**: male 1.77 (0.57 acute, 1.19 overuse); female 2.33 (0.85, 1.46) **Swim:** male 1.94 (0.95 acute, 0.97 overuse); female 3.25 (1.24 acute, 1.92 overuse) **Run:** male 3.15 (1.19 acute, 1.89 overuse); female 2.45 (0.85 acute, 1.48 overuse) **Soccer:** male 4.90 (3.64 acute, 1.18 overuse); female 5.32 (3.11 acute, 2.14 overuse)
Alricsson and Werner (2006)	Observational	20 asymptomatic skiers from northern Sweden 10 male, 10 female 3 male and 2 female dropouts over 5 years.	**% of skiers with low back pain:** 46.7% of skiers reported low back pain at 5-year follow-up

Study reference	Study design	Participants	Results: Type of injury. Anatomic location. Severity.
Alricsson and Werner (2005)	Retrospective questionnaire (May and December 2002)	High school students in Sweden 120 cross-country skiers 993 regular high school students Mean age 18 years	**% of skiers injured by anatomic location:** neck 11%, back 26%, knee 18%, hip 4%, ankle 16%, shoulder 7% **Control group injuries:** neck 21%, back 37%, knee 28%, hip 7%, ankle 16%, shoulder 13%
Bahr et al. (2004)	Retrospective self-reported questionnaire	257 cross-country skiers, 199 rowers, 278 orienteers, 197 control subjects Age: men 23 +/- 5; women 21 +/- 4 Years of competition: men 11 +/- 5; women 10 +/- 3	**% of skiers with LBP:** 65.4% LBP ever, 63.0% LBP during the previous 12 months **Severity:** 19.1% of skiers missed training because of LBP, 5.8% of skiers missed competition because of LBP
Bergstrom et al. (2004)	Retrospective injury questionnaire (three times in one year)	45 Norwegian ski high school athletes aged 15–19 years Alpine and freestyle skiing combined *n* = 23, cross-country and biathlon combined *n* = 22 Competitive cross-country skiers males *n* = 10, females *n* = 7	**% of all skiers reporting injuries to anatomic locations:** 65% back, 75% knee Significantly more overuse injuries and pain were found in the back (65%) and in the knee (75%) than in other anatomic locations ($p < 0.01$) **% of cross-country skiers reporting injuries to anatomic locations:** back 77%, neck 18.1%

Study reference	Study design	Participants	Results: Type of injury. Anatomic location. Severity.
Butcher and Brannen (1998)	Retrospective self-reported questionnaire	833 midlevel participants (not elite yet expert skiers) in 1996 American Birkebeiner cross-country ski marathon (55km) 78% responders were men, mean age 40.5 years	**% of injuries by anatomic location (during the ski marathon):** ankle/foot 36%, hand/wrist 28%, hip/thigh 12%, shoulder/elbow 11%, knee/leg 8% **% of injuries by severity (during the year):** most were minor; only 19.9% of skiers reported lost training
Ueland Ø and B (1998)	Retrospective observation of medical records	Medical records from four types of skiing activity injuries: cross-country skiing, downhill skiing, telemark skiing, and snowboarding	**% of injuries by anatomic location:** 35% lower extremity, 35% upper extremity, 9% trunk **% of injuries by severity:** 63% low severity not requiring hospitalization, 28% moderate
Lindsay et al. (1993)	Observational	18 elite cross-country ski athletes (Canadian), 15 controls Aged 17–35 years	**% of injuries by anatomic location:** 39% elite skiers had SI joint dysfunction, 0% of controls
Orava et al. (1985)	Observational 10-year period	187 cross-country skiers (166 competitive, 28 recreational skiers)	**% of injuries (ski related) by anatomic location:** 16.7% shoulder; 21.8% back and trunk; 30.8% ankle, foot, heel **% of injuries (not ski related) by anatomic location:** 35.3% knee; 34.5% lower leg; 15.5% ankle, foot, heel; 11.2% pelvis, hip, groin **% of all injuries by anatomic location:** lower extremity 74.7%, trunk 18.6%, upper extremity 6.7%

2.4 Risk Factors for Injuries in Cross-Country Skiing

Injury risk factors are considered to be intrinsic (related to the athlete) or extrinsic (sport related rather than athlete related; Ristolainen et al., 2014). Studies of sport-related injury risk are difficult to compare as the reporting strategies and injury definitions have been varied (some studies reported all injuries, others only traumatic, others only overuse, others only injuries from hospital and doctor office records; see Table 2.1). Ristolainen (2012) and Bahr et al. (2004) have addressed the problem of incomparable injury-reporting strategies, and injury definitions across study populations, by studying large cohorts of endurance athletes from different endurance sports. Ristolainen et al. (2014) investigated injury and risk factors in a cohort of 446 elite athletes from the sports of cross-country skiing, swimming, long-distance running, and soccer. Bahr et al. (2004) investigated low back pain in a cohort of 1,201 participants from cross-country skiing, orienteering, rowing, and nonathletic controls. The findings from these two large cohort studies make up the majority of the data on risk factors for injury in cross-country skiers, and thus will feature heavily in the next two sections on intrinsic and extrinsic risk factors for injury in cross-country skiing and other endurance sports.

2.4.1 Intrinsic risk factors for injury in cross-country skiing and other endurance sports.

Intrinsic risk factors for injury are those biological and psychosocial factors related to the individual, such as age, gender, BMI, injury history, and, in the case of female athletes, menstrual status (Ristolainen, 2012). Intrinsic risk factors are not considered easily modifiable. Of all the intrinsic risk factors studied, previous injury (of any anatomic region, any tissue type, and any mechanism acute or chronic) has been reported to be a more important predictor of sport injury than psychological, psychosocial, physiological, and anthropometric factors (Ristolainen et al., 2014). Gender-related risk for acute and overuse injuries in top-level athletes from cross-country skiing, swimming, long-distance running, and soccer is small; however, some gender differences in the specific anatomical locations of injuries as well as in specific injuries in specific sports have been seen. A higher proportion of the male athletes reported acute upper back injuries, and overuse injuries to the posterior thigh, while a higher proportion of the female athletes sustained acute injuries to the heel, and to ligaments in general (Ristolainen et al., 2009). When considering the type of sport, a higher proportion of male soccer players sustained an overuse injury to the posterior thigh, a higher proportion of female soccer players sustained acute ligament injuries, and female cross-country skiers reported a higher rate of overuse injuries to the heel (Ristolainen et al., 2009). Thus, when planning a surveillance and/or training schedule for endurance athletes, it would be wise to take into account each individual's gender, past history of any injury, and the menstrual cycle regularity of the women, as any and all of these factors may influence the future injury risk.

2.4.1.1 Hamstring length and low back pain.

Improvement in hamstring length occurred in cross-country skiers after a preseason dance training programme, and the same cross-country skiers also reported a reduction in back pain compared to those who did not participate in the dance training programme, suggesting that improved hamstring length is associated with reduced low back pain (Alricsson & Werner, 2004). This is a justification for including hamstring length in our study even though it is not part of the MCS battery of tests. Hamstring length was also included to allow comparison with the elite rowers studied previously using a comparable methodology (Newlands, 2013).

2.4.1.2 Trunk muscle endurance and low back pain.

The trunk muscles tended to be weaker among those who experienced recurrence of low back pain in the follow-up year compared with those without recurrence of low back pain; however, this relationship was not observed in those reporting first-time back pain (Biering-Sorensen, 1984). As no studies were found to report the relationship of trunk muscle endurance to injury in cross-country skiers, these tests were included in the current study. Trunk muscle endurance testing was also included to allow comparison with the elite rowers studied previously using a comparable methodology (Newlands, 2013).

2.4.2 Extrinsic risk factors for injury in cross-country skiing and other endurance sports.

Extrinsic risk factors for injury are those factors considered to be sport related rather than athlete related, such as training errors, sudden increases in overall training volume (Bahr et al., 2004), sudden increases in running volume (Bahr et al., 2004), and insufficient rest and recovery time (Ristolainen, 2012). Extrinsic risk factors are considered more readily modifiable than intrinsic risk factors. When considering training volume, low back pain occurred more frequently during periods of intense training and competition for cross-country skiers, rowers, and orienteers (Bahr et al., 2004). Injury risk is reported to be higher in endurance athletes with less than 2 rest days per week during the training season, greater than 700 hours training per year, and greater than 12 years of active training (Ristolainen et al., 2014). Variety of training activity may be important also, as participating in another sport weekly for 3 or more years protected against low back pain in Swedish adolescent elite cross-country skiers (Alricsson & Werner, 2006). Elite adult cross-country skiers were twice as likely to experience low back pain when using the classic ski technique compared to the skate technique (Bahr et al., 2004). It should also be noted that for cross-country skiers, while a variety of physical activities may have a protective effect on injury, Ristolainen et al. (2010) reported most acute and overuse injuries to cross-country skiers occurred during exercise outside of their competitive sport. Thus, variety of training activity (different sports, as well as variation of cross-country ski styles), careful attention to training hours, and adequate rest days should be considered when planning a training schedule for an endurance athlete.

2.4.3 Summary.

At this time consistent predictors for future athletic injury are previous injury (Chorba et al., 2010; Fulton et al., 2014; Ristolainen, 2012; Ristolainen et al., 2014) and training load/exposure hours (Bahr et al., 2004; Ristolainen, 2012). As an intrinsic, nonmodifiable predictor, previous injury is a useful factor for classifying athletes at an elevated risk for injury, but it cannot realistically be manipulated to prevent future injury (Ristolainen, 2012; Ristolainen et al., 2014). Training load/exposure hours can be used to classify athletes at an elevated risk for injury, and can then be modified according to the evidence and recommendations in the literature (Ristolainen, 2012; Ristolainen et al., 2014). However, gathering knowledge of the individual athlete's physical, social, and emotional needs, and combining this with the scientific knowledge about injury risk, will optimise the design of an athlete-specific training programme (Cañeiro, Ng, Burnett, Campbell, & O'Sullivan, 2013).

Prevention of the initial injury is the best mechanism to reduce future injury (Florenes, 2010; Ristolainen, 2012). Cross-country ski injury prevention research continues to evolve in the first two steps of the van Mechelen et al. (1992) sequence of injury prevention model. An important goal of injury prevention research is to determine which tests and measures can predict whether an athlete will become injured

(Cook et al., 2006a, 2006b; Florenes, 2010). While previous injury and other intrinsic risk factors may help classify an athlete into an at-risk group, these risk factors are difficult to modify (Bahr, 2016; Ristolainen, 2012). Extrinsic risk factors such as training errors, movement impairments, sport equipment faults, and sport technique errors are more easily modified (Ristolainen et al., 2014). The ability to identify athletes at an elevated risk for injury due to these extrinsic risk factors has been proposed to be the goal of preparticipation screening and whole body movement screening (Bahr, 2016; McGill et al., 2012).

2.5 Screening Tests in Sports Medicine

In sports injury prevention, the objective is early intervention to minimise risk factors before injury occurs (Bahr, 2016). Sports scientists and sports medicine practitioners screen athletes using a variety of tests and measures with the intention to prevent injury and illness, reduce injury and illness, rehabilitate from injury, or learn more about optimal athletic movement (Kiesel et al., 2007; O'Connor et al., 2011; Schneiders et al., 2011). The tests used vary from impairment-level tests such as muscle length and strength measures; functional tests such as the Star Excursion Balance Test (SEBT) or triple hop for distance; and more recently whole body movement pattern testing such as the MCS, FMS, and Athletic Ability Assessment (AAA). Traditionally, sports coaches and sports medicine teams have used individual impairment tests such as muscle length and strength tests, and joint range of motion tests, to assess sports participants prior to and during competitive seasons in an attempt to identify individuals who may be at an increased risk of sustaining an injury (McGill et al., 2012). These impairment-level measures identify the specific impairment but do little to assess the more complex question of the quality and precision of whole body movement patterns (Cook et al., 2014a). Assessing whole body fundamental movements may provide an opportunity to create a more individualised training programme focusing on changing or modifying movement patterns, instead of focusing on the rehabilitation of specific joints and muscles (Schneiders et al., 2011).

Whether the movement evaluations have been at the impairment level, or the more recently popularised whole body movement pattern level, there is yet to be consistency in reports of movement evaluation being predictive of future injury. The recent focus on whole body movement screening is in response to the recognised inadequacies of individual impairments tests when attempting to predict how the body will move as a coordinated whole (Cook et al., 2014b; Gamble, 2013). The following sections discuss the whole body movement screens found in the recent literature.

2.6 Whole Body Movement Screening

A whole body movement screen is a collection of movement tasks designed to identify and describe movement competency (or lack thereof) and determine whether the individual's movement requires further investigation (Cook et al., 2014b). The fundamental movement patterns that compose a whole body movement screen are basic movements used to simultaneously test range of motion, stability, and balance (Cook et al., 2006a, 2006b; Kiesel et al., 2007). Evaluating the quality, quantity, and repeatability of whole body fundamental movements may improve the identification of efficient and less efficient movers, and may potentially identify participants at risk of injury (Cook et al., 2014a; Gamble, 2013). All sports participants move their bodies in complex coordinated patterns to perform the specific characteristics of their sporting activity (Gamble, 2013). Readiness for sports participation may thus be better assessed by evaluating whole body movements rather than the traditional impairment-level testing of joint range of motion and muscle strength and length (Cook et al., 2014a).

Three whole body movement screens were identified in the literature search: the Functional Movement Screen (FMS; Cook et al., 2006a, 2006b), the Movement Competency Screen (MCS; Kritz, 2012), and the Athletic Ability Assessment (AAA; McKeown, Taylor-McKeown, Woods, & Ball, 2014). The FMS has been studied more extensively than the MCS or the AAA. The attraction of these movement screens is their time- and cost-effectiveness, and the relative simplicity to perform and evaluate the screen even with a large study population or sports team. Before a screening tool can be used to assess injury risk, it must be reliable and valid (Cook et al., 2006a, 2006b; Gulgin & Hoogenboom, 2014; McCunn, aus der Fünten, Fullagar, McKeown, & Meyer, 2016), and have correlation with injury (Chorba et al., 2010; Kiesel et al., 2007). Sections 2.6.1, 2.6.2, and 2.6.3 summarise the development of the MCS, FMS, and AAA tools.

2.6.1 Movement Competency Screen (MCS).

The MCS is composed of five movement tasks considered common to sport and activities of daily living: double leg squat, lunge and twist, push-up, bend and pull, and single leg squat. The MCS was developed by Kritz (2012) to be a battery of tests that is reliable and valid for establishing an individual's movement competency irrespective of their chosen sport, and then to be used to guide exercise prescription for that individual. Another aim of the MCS was to streamline the language of communication and understanding of movement competency between medical and coaching staff involved with the care of athletes (Kritz, 2012). The quality of each MCS movement is graded between 1 and 3, with a 1 being awarded for poor movement competency, and a 3 awarded for a movement without compensatory patterns. The individual movement grades indicate the level at which the athlete can perform the movement pattern correctly and safely, with level 1 requiring the body weight to be attenuated, level 2 challenging the movement pattern with body weight, and level 3 adding external load to the body. The sum of the individual movement scores creates the MCS score, with a perfect total MCS score being 21. The component motions of the lunge and twist and bend and pull are scored separately; thus, there are seven individual movement scores collated to derive the total MCS score.

The interrater reliability of the MCS score is reported to be excellent (ICC = .77–.91; Dewhirst et al., 2015; Kritz, 2012; Milbank et al., 2016; Reid et al., 2015). The results of these studies support the use of the total MCS score based on the consistency between raters, and between testing sessions.

The scores of the individual movements that compose the MCS should be interpreted with care as there is much less agreement between raters on the scores, especially for the more complex movements of bend and pull, single leg squat, and twist (Dewhirst et al., 2015; Milbank et al., 2016; Reid et al., 2015).

The MCS is currently in use by High Performance Sport New Zealand (HPSNZ) as a component of their overall screening strategy for all elite athletes. The MCS has also been used to evaluate the movement competency of military recruits (Milbank et al., 2016), elite rowers (Newlands, 2013), high school netball players (Reid et al., 2015), and elite dancers (Lee, 2015).

2.6.2 Functional Movement Screen (FMS).

The FMS is composed of seven movement tasks: deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, push-up, and rotary stability. The FMS was developed by Cook et al. (2006a), and is designed to be a screen, to determine body weight resisted movement competency, during fundamental movements that incorporate mobility, stability, and motor control. Specific equipment is necessary to complete the FMS. The quality of each FMS movement is graded from 0 to 3; 0 is scored if there is any pain during the movement, and 3 is scored if the movement is completed without compensatory patterns. Thus, a perfect score for each movement is 3, and a perfect score on all components of the FMS would yield a total FMS score of 21. The developers of the FMS (Cook et al., 2014b) believe if an individual scores within the norms on the FMS (indicating good functional movement, and thus not requiring movement reeducation), that individual can still be at risk of injury because of several factors, including but not limited to poor landing mechanics, strength, endurance, agility, or power deficits. However, the individual who has scored within the established norms, and thus has demonstrated movement competency, is likely to possess the fundamental movement capability necessary to improve those higher-level performance tasks (landing, agility, strength, power, endurance) that may be deemed injury risks (Cook et al., 2014b).

When scored either in real time or using video analysis, the FMS has poor to excellent interrater reliability for total scores (ICC = .37 - .98) depending on the experience of the testers (Cook et al., 2014a; Gulgin & Hoogenboom, 2014; Jade & Street, 2013; Schneiders et al., 2011; Smith, Chimera, Wright, & Warren, 2013). There is poor to excellent reliability for scoring of individual test movements (ICC = .30 - .89; Cook et al., 2014a). The FMS is currently the more commonly researched whole body movement screen, and has been used to evaluate movement patterns in military and police populations (Bock et al., 2016; O'Connor et al., 2011), athletic populations (Chorba et al., 2010; Hall, 2014; Kiesel et al., 2014; McGill et al., 2012; Wiese et al., 2014), and a generally young active population without specific sports affiliations (Schneiders et al., 2011).

2.6.3 Athletic Ability Assessment (AAA).

The AAA is composed of the prone hold, side hold (left and right), overhead squat with 10kg Olympic bar, single leg squat (left and right), walking lunge with 20 kg Olympic bar, forward hop (left and right), lateral bound (left and right), push-up, and chin-up. The AAA was designed by McKeown et al. (2014) to be used as an assessment tool for athlete profiling, as well as to assess changes in functional movement ability over time. Each movement in the AAA screen is assessed for standardised criteria of performance, which is divided into three subsections for each movement. Unlike the FMS and MCS, each AAA movement task is scored by the sum of the scores from the three subsections of the movement. Each sub3section of a movement is scored out of a possible 3 points, with 1 being poor, unable to perform specific task; 2 being inconsistent performance of specific task or slight deviation from ideal; and 3 being perfect performance of specific task. Thus each movement has a perfect score of 9 points, and a perfect performance of the AAA would result in a score of 117 points. Intra- and interrater reliability for the AAA composite score were excellent (ICC = .97 for intrarater and .96 for interrater). At this time the AAA has been used to evaluate movement patterns in female semiprofessional football (soccer) players (McKeown et al., 2014), male Australian Football League players (Woods, McKeown, Haff, & Robertson, 2016), and as part of talent identification assessment in Australian Football (Woods, Banyard, McKeown, Fransen, & Robertson, 2016).

2.6.4 Whole body movement screens and injury prediction.

Using whole body movement screen scores to predict individuals who may be at a higher risk of injury may seem intuitive; however, at this time there is little conclusive support in the literature for such a straightforward correlation. While these movement screens were not initially developed to predict injuries, or for use in injury prevention research, there has been discussion on the use of movement screen scores to predict sports participants' risk for injury (Chorba et al., 2010; Kiesel et al., 2007; O'Connor et al., 2011). It has been hypothesised that impaired movement patterns due to muscle strength or length impairments, nonstandard joint range of motion, nonideal static alignment, or poor dynamic balance may predispose sports participants to performance-limiting injury (Chorba et al., 2010; Cook et al., 2006a). At this time, whole body screens are reliable and practical for determining movement competency in individuals, but not for predicting injury. Other authors have explored the role of detailed movement assessment in the context of maladaptive movement patterns (pain avoidance, or pain provocation) being the cause of repeated tissue microtrauma and subsequent pain (O'Sullivan, 2005; Sahrmann, 2014). Cook et al. (2006a) uses the same concept in suggesting that an important factor in preventing injuries and improving performance is to quickly identify deficits in mobility and stability because of their influences on creating altered and potentially injurious motor programmes throughout the kinetic chain. O'Sullivan (2005) and Sahrmann (2014) provide examples of pain avoidance or pain-provoking movements positively associating with increased low back pain, and then show the low back pain is improved when the movement impairment is identified and corrected. Whole body functional movement screening may identify maladaptive potentially injurious movement patterns just as effectively, and more efficiently than detailed muscle and joint impairment level testing (even in the absence of existing pain or tissue dysfunction) (Cook et al., 2014b; Gamble, 2013; Sahrmann, 2014). If this is so, then as suggested by McCunn et al. (2016) movement screens may well provide practitioners with a greater holistic understanding of their athletes' physical capabilities and potential tissue microtrauma, which may then lead to reduction in injury frequency. The next sections, 2.6.4.1 and 2.6.4.2, describe the work published thus far regarding injury prediction and the MCS and FMS tools. The AAA has not yet been used in any published injury prediction studies.

2.6.4.1 MCS and injury prediction.

In the few studies investigating the relationship between MCS scores and new injury (Lee, 2015; Milbank et al., 2016; Newlands, 2013), MCS scores have not consistently been positively correlated with injury incidence. A lower MCS score did positively correlate with new physical complaints resulting from performance, rehearsal, or class, in a cohort of dancers (Lee, 2015). A lower MCS score did not correlate with low back pain, ache, or discomfort (with or without referral to the buttocks or legs) present for greater than one week, and/or interrupting at least one training session in rowers (Newlands, 2013). A lower MCS score did not correlate with injuries reported to the medical team during service training in a cohort of United States Naval Academy recruits (Milbank et al., 2016). A lower MCS score did positively correlate with poor performance on the Physical Readiness Test (PRT) in a cohort of female United States Naval Academy recruits (Milbank et al., 2016). In the future, correlations such as this may influence military recruit selection, preparation, and subsequent injury during training (Milbank et al., 2016).

Kritz (2012) performed a prospective 12-month pilot study to examine the ability of the MCS to predict performance and injury in elite athletes (n = 91) from field hockey, netball, and basketball. The findings of this pilot study are limited due to the relatively small number of athletes from each sport. However, there was some evidence that athletes scoring below a 3/3 on trunk movement were at increased risk of trunk injury (Kritz, 2012).

Newlands (2013) investigated the relationship between MCS score and the risk of low back pain in elite New Zealand rowers (n = 76) using a prospective 12-month injury-reporting protocol. Rowers with an MCS score greater than 16/21 were more likely to have a new episode of low back pain than those with a lower score; however, this finding was not statistically significant (p = .08). Suggesting that athletes with good movement quality are more likely to experience injury is counter to the commonly held belief that poor movement quality is associated with greater injury incidence. This is an example of the inconclusive nature of the current knowledge about movement competency and injury incidence. Perhaps the rowers who sustained injuries were those whose movement capabilities allowed them to train harder and longer, thus putting them at risk for injury due to their elevated training load (a known risk factor for injury) rather than their movement quality.

Lee (2015) investigated the relationship between MCS score and the risk of injury in elite New Zealand dancers (n = 66) using a prospective 12-month injury-reporting protocol. There were more injuries reported from the dancers who had an MCS score of </= 23/36 (p = .035). This finding is consistent with the commonly held belief that poor movement quality is associated with injury. It should be noted that this study used a modified version of the MCS that included jump landings; hence, total scores are out of 36.

The results of these correlation studies are conflicting largely due to the variation in sample size, study population, use of progressive versions of the MCS, and type of injury used (any physical complaint, medical report of injury, and low back pain were the injury definitions used in these MCS studies). Larger sample sizes, consistency in the version of the MCS, and consistency of injury definition should be the focus of future investigations of correlation between MCS score and new injury. However, these current studies do establish baseline MCS scores for a variety of active populations, and begin to build the evidence for MCS use in athletic screening, injury prediction, and, eventually, perhaps injury prevention.

2.6.4.2 FMS and injury prediction.

The relationship between FMS scores and injury incidence is more widely published; however, the results remain variable. There are reports of significantly positive correlations between FMS score and musculoskeletal injury incidence (Chorba et al., 2010; Kiesel et al., 2007; Kiesel et al., 2014; O'Connor et al., 2011), and reports of insignificant or no correlation between FMS score and musculoskeletal injury incidence (Hall, 2014; Warren et al., 2015; Wiese et al., 2014).

Three research teams have reported significant positive correlations between low FMS scores, </= 14/21, and new musculoskeletal injuries ($p < .05$) (Chorba et al., 2010; Kiesel et al., 2014; O'Connor et al., 2011). Kiesel et al. (2014) studied FMS scores and serious time loss injury (greater than 3 weeks on the injured reserve list) in 238 professional American football players during a preseason period. A combination of FMS score </= 14/21 and at least one movement asymmetry was highly specific for serious time loss injury during the preseason (specificity 0.87). O'Connor et al. (2011) assessed 874 Marine officer candidates to determine whether FMS scores could predict which officer candidates would seek medical care for physical damage to any part of the body as a result of participating in physical training. There was a higher injury risk among candidates who had scores </= 14/21. Chorba et al. (2010) investigated whether the FMS tool would predict musculoskeletal injuries requiring medical care during the competitive season in 38 female collegiate athletes from soccer, volleyball, and basketball teams. An FMS score of </= 14/21 was significantly associated with injury ($p < .05$). To summarise, professional athletes, military officer candidates, and collegiate athlete populations have all been shown to be at higher risk for musculoskeletal injuries requiring medical care if their FMS score is </= 14/21.

In contrast to these positive relationships, no statistically significant relationship between FMS score and musculoskeletal injuries requiring medical care was found in three collegiate-level studies. In these studies, sample size varied from 81 to 167, and populations varied from single sports (football; Hall, 2014; Wiese et al., 2014) to a variety of sports (football, basketball, volleyball, cross-country running, track and field, swimming and diving, soccer, golf, and tennis athletes; Warren et al., 2015). In summary, FMS scores have not been predictive of musculoskeletal injuries requiring medical care in collegiate-level team sport and individual sport athletes.

The contrasting correlations reported between FMS scores and new injury (even between populations from the same sport) suggest accurate injury prediction may be multifactorial, with influence from whole body movement competence, as well as other intrinsic and extrinsic risk factors. However, when combining the FMS with additional sport-specific movement tests and fitness scores in collegiate basketball players, no definitive correlations with new musculoskeletal injuries requiring medical care were found (McGill et al., 2012). Further investigation of possible multifactorial predictors of injury in a wide variety of active populations is warranted.

2.6.5 Summary.

The intention of these whole body movement screens is to identify and describe movement competency (or lack thereof), and determine whether the individual's movement requires further investigation (Cook et al., 2014b). Regardless of the rater experience with a screening tool, there is high interrater and intrarater reliability for the overall score for the FMS (Cook et al., 2006a, 2006b; Cook et al., 2014a, 2014b; Gulgin & Hoogenboom, 2014; Jade & Street, 2013; Smith et al., 2013), MCS (Dewhirst et al., 2015; Milbank et al., 2016; Reid et al., 2015), and AAA (McKeown et al., 2014). This reliability across raters of varied experience makes the overall scores of these screening tools practical for use in a variety of sports and exercise settings. However, the subjectivity of the scoring, the complexity of multiple body parts moving in multiple planes, and the imprecision of some movement descriptions are areas requiring further refinement before the individual movement scores can be used independently in research or clinical settings.

None of the movement screens that appear within the scientific literature currently has enough evidence to justify the label of “injury prediction tool.” However, they may provide practitioners with greater holistic understanding of their athletes’ physical capabilities (McCunn et al., 2016), and this in turn may reduce injury rates by virtue of improved athlete-specific training programmes. As whole body movement screening tools currently stand, they may be insufficiently sensitive to the specific demands of a sport to be of use as the sole predictor of future injury for specific sports. Adding psychological trait and state assessment to a preparticipation screen, in combination with a whole body movement screen, and additional sport-specific tasks may improve the usefulness of a screen for specific populations. This would be consistent with the growing body of work finding psychological and social factors are important to injury, injury recovery, and return to athletic performance (Cañeiro et al., 2013; Van Mechelen et al., 1996).

2.7 Justification for the Use of the MCS in This Study

Although there is limited published research on the MCS, this screening tool was selected for the current study for a number of reasons: (a) to add to the body of published work using the MCS; (b) to allow comparison of study outcomes with previously conducted work using the MCS in rowers (Newlands, 2013), netball players (Reid et al., 2015), dancers (Lee, 2015), and U.S. Navy recruits (Milbank et al., 2016); (c) because the primary investigator could become proficient in the use of the MCS without the financial burden of proprietary training; (d) because one of the primary investigator's advisory staff had prior knowledge of the MCS, whereas none of the advisory staff had knowledge of the FMS or AAA; and (e) we were interested in how cross-country skiers would perform on a whole body movement screen given the high level of movement coordination required for successful cross-country skiing.

2.8 Conclusion

Cross-country ski injuries, risks for injury, injury prevention research, and pre participation movement screening studies have been reviewed. There is evidence that cross-country ski injuries occur more often to the lower extremities, and the mechanism of injury is overuse more often than acute traumatic events. Injury incidence rates for cross-country skiers appear to be similar to those reported by other endurance athletes (e.g., cyclists, orienteers, and long-distance runners), and the rates are low (2.0 - 2.8 injuries per 1,000 hours) compared to contact sports played in teams (e.g., 5.1 injuries per 1,000 hours for soccer players; Ristolainen et al., 2009). However, drawing useful comparisons between different cross-country ski studies, and between cross-country skiing and other endurance sports, is difficult due to the variability in injury recording and reporting. There is agreement in the literature that previous injury (McGill et al., 2012; O'Connor et al., 2011; Ristolainen et al., 2014; Van Mechelen et al., 1996) and training/exposure hours greater than 700 hours per year (Ristolainen et al., 2014) are risk factors for injury in cross-country skiers. While the MCS may be a useful preparticipation movement screening tool, there are no normative scores for the MCS (or any other whole body movement screen) in the competitive cross-country ski population. Precise comparable data are still needed about movement competency, injury incidence, injury severity, and mechanisms of injury in cross-country skiing before preventive measures can begin to be studied. This study will provide MCS scores for a sample of elite cross-country skiers, report the injury type and injury incidence per 1,000 exposure hours for cross-country skiers, and examine the relationship between new injury and MCS score, hamstring length, trunk muscle endurance, previous injury, and training/exposure hours. Thus, it will contribute to the body of knowledge about cross-country skier movement patterns and injuries.

2.9 Statement of Hypotheses

Considering the literature reviewed in this chapter, the primary hypothesis was that new injury is associated with poor movement competency (assessed by the MCS score) in cross-country skiers. Our secondary hypotheses were that new injury is associated with self-reported intake variables: (a) a history of injury, (b) a long career in cross-country skiing, (c) high training hours, (d) a high number of training hours spent running, and (e) a high number of training hours spent roller skiing; and that new injury is associated with intake muscle measures: (f) poor trunk muscle endurance ratio (using the ratio of trunk flexor to trunk extensor endurance time recorded from the McGill trunk flexor muscle endurance test, and the Biering-Sorenson trunk extensor muscle endurance test), and (g) reduced ASLR (where reduced hip flexion ROM indicates short hamstring muscles). To test these hypotheses, this study of NCAA and professional cross-country skiers collected and analysed subject demographics; intake physical measurements (MCS, hamstring length, and trunk muscle endurance); and monthly injury, training, and racing reports from 12 consecutive monthly surveys.

In addition to the primary and secondary hypotheses, this study also aimed to report mean injury incidence in cross-country skiers (number of new injury reports per subject per 1,000 hours of training/exposure). Once injury incidence was calculated, we sought to determine if injury incidence was different between: (a) the ski season and off-season, (b) traumatic and nontraumatic injuries, and (c) injuries by anatomic location.

This study also aimed to describe the characteristics of a group of NCAA and professional cross-country skiers in the northeastern USA using subject demographics; intake physical measurements (MCS, hamstring length, and trunk muscle endurance ratio); and monthly injury, training, and racing reports from 12 consecutive monthly surveys.

3 Methods

A group of professional and National Collegiate Athletic Association (NCAA) cross-country skiers volunteered to participate in this study. Data collected from each subject included demographics, MCS video, hamstring length (using the Active Straight Leg Raise test, Section 0, Figure 3.7), and trunk muscle endurance times (using the Biering-Sorenson trunk extensor muscle endurance test, Section 3.7.2, Figure 3.8, and the McGill trunk flexor muscle endurance test, Section 3.7.3, Figure 3.9). These tests were selected to allow comparison of our cross-country skier data with the data from elite rowers in a previous study using similar methodology (Newlands, 2013). The subjects were then surveyed monthly for 12 consecutive months to determine the duration and type of training each month, as well as any injuries, and any changes in training or competition due to injury. All data were then examined to determine any relationship between new injury reports over the 12 months of the study and the (a) MCS score, (b) hamstring length, (c) trunk muscle endurance ratio, (d) injury history, (e) ski history, (f) demographic data, (g) training type and duration, and (h) racing reports. Demographic, intake physical test results, and monthly training and racing data were used to describe the study cohort, report the injuries sustained, report the quantity of training performed, report the quantity of training lost or modified to injury, and calculate the injury incidence.

3.1 Study Design

This study was a prospective longitudinal cohort design.

3.2 Subjects

Eligible study subjects were members of a professional cross-country ski team, or members of a university cross-country ski team competing at the NCAA level during the 2014–2015 northern hemisphere winter. A convenience sample of 71 eligible cross-country skiers enrolled in this study.

Ethical approval was granted by the Institutional Review Boards of: The University of Vermont (see Appendix 7.2); Auckland University of Technology (Appendix 7.1); Middlebury College (Appendix 7.3); and Bowdoin College (Appendix 7.4).

3.3 Recruitment of Subjects

Recruitment was a two-step process:

(i) The coaches of northeastern American university cross-country ski teams, and northeastern American professional ski teams, were contacted by e-mail to establish their interest in the study. Based on team roster lists this created a potential pool of 176 subjects. If possible, an in-person meeting with the coach was scheduled. Two professional teams and four NCAA ski teams expressed interest in participating. One professional team, four NCAA, and two preparatory school ski teams declined to participate.

(ii) The primary investigator attended a ski team meeting. The primary investigator explained the study process and invited the skiers to participate. At this same meeting, skiers who agreed to participate were enrolled in the study.

3.3.1 Sample size calculation.

To test the primary hypothesis that MCS score is related to new injury, a sample size calculation was performed (Kane, 2015). A sample size of 35 in each group (injured and not injured) will have 80% power to detect a difference in mean MCS scores of 1.0

(the difference between noninjured subjects' mean MCS score of 14, and injured subjects' mean MCS score of 13) assuming that the common standard deviation is 1.5 using a two group *t*-test with a .05 two-sided significance level (Kane, 2015). Recruitment aimed to enrol as many subjects as possible to ensure 70 subjects were retained throughout the 12 months of the study. Accepting that 20% or more of recruited subjects would not complete the 12 monthly surveys, the minimum number of subjects needed was 88. Due to subject availability and enrolment time constraints, 71 subjects enrolled in the study.

When the sample size calculation was performed, the MCS scores available for reference were those from Newlands's (2013) study of rowers (mean MCS for men 15.6, and for women 15.0); Vanweerd's (2013) study of female netball players (mean MCS score 13.6); and Dewhirst et al.'s (2015) study of adolescent cross-country skiers (mean MCS score 11.4), which was our pilot study. Taking into account these scores, the lack of any sensitivity data for the MCS, and the low sensitivity values reported for the FMS (Chorba et al., 2010; Hall, 2014; Kiesel et al., 2007; O'Connor et al., 2011), we made our best estimate of <14/21 for the cutoff MCS score.

3.3.2 Enrolment process.

After signing the consent form (see Appendix 7.5), a unique identifier was assigned to each subject for data tracking. Subjects then completed an electronic intake demographic survey (see Appendix 7.8) and the first of 12 electronic monthly injury and training surveys (see Appendix 7.9). Next, subjects were videoed performing the MCS. Lastly, measures of each subject's hamstring length and trunk flexor and extensor muscle endurance were made. Enrolment occurred at a ski team meeting most convenient to each participating team, on a rolling schedule between August and December of 2014.

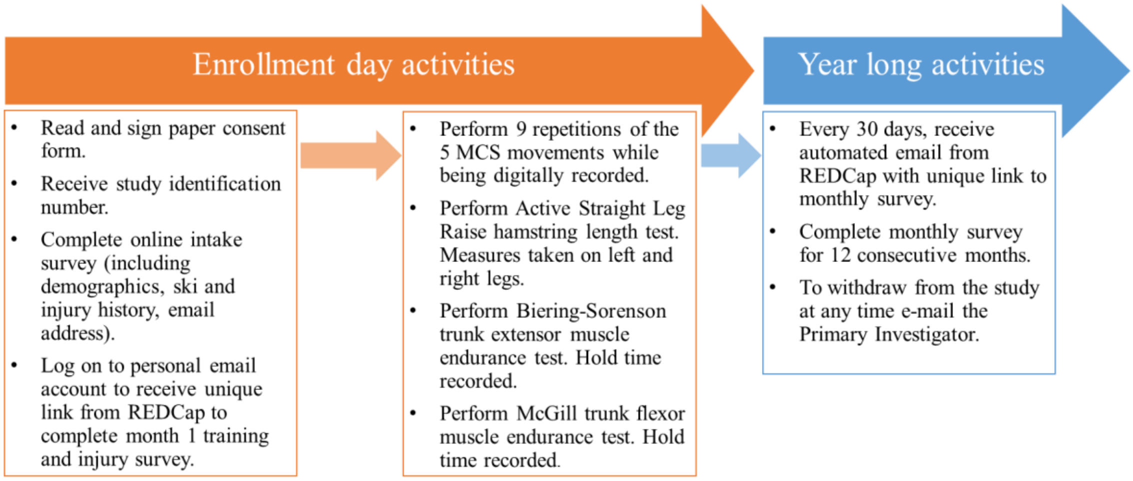

Figure 3.1. Flow of subjects through the study.

3.4 Intake and Monthly Surveys

3.4.1 REDCap (Research Electronic Data Capture).

The intake survey and all monthly surveys were created, collected, and managed using REDCap (Harris et al., 2009) electronic data capture tools hosted at the University of Vermont. This software was used due to the no-cost availability, and the enhanced security of personal health information behind the firewalls of the University of Vermont and University of Vermont Medical Center. The primary investigator created the survey documents using the REDCap software. The survey questions were developed after discussing cross-country skier injury with the coaches of potential study subjects and reviewing the current literature. The questions and survey layout were modelled after those used in a previous study of injury incidence in elite rowers (Newlands, 2013).

The survey developer can create and design REDCap surveys in a web browser that can engage potential respondents using a variety of notification methods; in this study, e-mail was used to communicate with athletes. REDCap surveys allow for a variety of question types, such as text boxes, multiple choice (single and multiple answer), file uploads, yes/no, true/false, and sliders (rating scales). There are also advanced question features that may be used, such as auto-validation, branching logic, and stop actions. REDCap is a secure, web-based application designed to support data capture for research studies, providing (1) an intuitive interface for validated data entry, (2) audit trails for tracking data manipulation and export procedures, (3) automated export procedures for seamless data downloads to common statistical packages, and (4) procedures for importing data from external sources. Participant responses may be easily exported to Microsoft Excel or to common statistical analysis packages (e.g., SPSS, SAS, R, and Stata).

3.4.2 Intake survey.

The intake survey was self-reported using the electronic REDCap survey created by the primary investigator and administered by the REDCap software (Appendix 7.8). The data of interest at initial intake included (a) age, (b) gender, (c) handedness, (d) weight, (e) height, (f) level of competition, (g) type of skiing, (h) age when began cross-country skiing, (i) previous injuries, (j) current injuries, (k) current medications, and (l) occupation. The contents of the intake survey were based on the survey used to study injury incidence in elite rowers (Newlands, 2013). The surveys were created with the required fields feature, thus ensuring all questions were answered.

3.4.3 Monthly surveys.

This study employed a self-reported REDCap survey (Appendix 7.9) created by the primary investigator and administered by the REDCap software. The contents of the monthly survey were based on the survey used to study injury incidence in elite rowers (Newlands, 2013). Using e-mail, the REDCap software distributed the monthly survey to each participant for 12 consecutive months. To reduce recall bias from month to month, subjects were encouraged to consult with their coaching and medical staff and refer to their personal training journals when completing the survey. The scope of this project did not include formal consultation with the coaching and medical staff during data processing or analysis. The surveys were created with the required fields feature, thus ensuring all questions were answered each month.

The variables of interest each month were (a) any changes in medications or occupation since the last survey, (b) amount and type of training, (c) amount and type of racing/competing, (d) type and severity of new or ongoing injury, and (e) effect of injury on training and/or racing.

Subjects received their survey links through the e-mail address they provided when enrolling in the study. REDCap was programmed to send a reminder to the subject every seven days until the survey was completed, or until the subject chose to formally withdraw from the study, or a month had passed.

All intake data from all subjects were retained for initial descriptive analysis. The data sets from subjects who responded to nine or more of the surveys, and included data from both the off-season and ski season, were retained for longitudinal analysis of training, racing, and injury reports. In this way, the maximum number of subjects were retained with the minimum amount of missing data for each study month. If a subject formally withdrew from the study, data already collected were retained for analysis purposes.

3.4.4 Injury definition.

Within the intake and monthly surveys, an injury was defined as: any episode of pain, ache, or discomfort that lasted for longer than one week (7 days), or caused the athlete to miss or modify any training or racing sessions (Newlands, 2013). A duration of one week was chosen to differentiate between workout-induced soreness and an actual injury (Newlands, 2013).

3.4.5 Location of injury.

Subjects selected the location of their injury from a list of body parts or regions. Subjects were given a free text box each month to further describe their injury(ies). During data analysis the body parts were grouped into body regions as follows: lower extremity, upper extremity, and trunk. The body region grouping followed methodology recommended by Fuller et al. (2006). Due to the small number of head, neck, and upper and lower back injuries, we chose to group all these into the trunk region as recommended by Fuller et al. (2006). Low back pain, acute fractures, and traumatic and nontraumatic injuries were included in the appropriate group, and also reported separately, due to current interest in these injuries from the global sporting community.

3.4.6 Injury severity.

The visual analogue scale (VAS) was used to record pain levels. The VAS provides a simple way to record subjective characteristics or attitudes that otherwise cannot be directly measured, such as estimates of pain intensity (McDowell, 2006). The VAS is described as a strong, clinically useful, reliable, and valid unidimensional measure of pain intensity (Kahl & Cleland, 2005). Each month, subjects were asked to rate their current, worst, and best pain level associated with their current injury using a linear VAS 100 mm long. Each linear VAS included a sliding bar between 0 (no pain) and 100 (worst pain ever) for the subjects to indicate their pain levels. Subjects were asked if any new injury was the "result of an accident, trauma, or a fall" (see Appendix 7.9), positive responses to this question were then classified as acute/traumatic, and all other injuries were classified as overuse/nontraumatic.

3.4.7 Training load.

Total monthly training load for each subject was calculated from the monthly survey responses. Each month, for each training or exercise activity, the survey collected the number of training sessions, and the duration of each training session (rounded to the nearest hour). Training load for on-snow skiing, other cardiovascular conditioning activities, and weight room training was calculated separately for further analysis.

3.4.8 Definition of seasons.

The ski season for this study was determined as December 2014 to April 2015 based on subject reports of on-snow training and dates of ski races. Off-season for this study period was August 2014–November 2014 and May 2015–November 2015.

3.5 Risk Factors for New Injury

All variables from the intake survey, intake physical measurements, and the monthly surveys were considered to be potential risk factors for new injury. Statistical analyses and clinical considerations were used to determine which variables were relevant risk factors.

3.6 Movement Competency Screening

Movement Competency Screen (MCS) video was recorded once for each subject at the time they enrolled in the study. The time commitment for the subjects, as well as the timeline for this master's thesis, did not allow follow-up MCS video at any other point during the study.

3.6.1 Procedure for recording Movement Competency Screening (MCS).

During the initial encounter with the subject, after the consent form was signed and surveys were completed, the subject performed the MCS. All subjects were asked to dress in sneakers and form-fitting shorts. The men were asked to perform the MCS without a shirt, and the women were asked to wear sports bras, to ensure the lumbar spine and scapulae would be visible for movement analysis. High Definition digital camcorders mounted on tripods were used to record each subject performing the five tests of the MCS tool. Prior to each test movement, subjects were shown a video of the movement from the front and side views, as well as a static photograph, and written instructions for each movement (Appendix 7.6). The primary investigator provided verbal description of each movement quoted from the previously developed script (Kritz, 2012). For the video of each movement used to educate the subjects in this study go to this link: https://www.youtube.com/playlist?list=PLEHzXgbFJbgAZpBddho8d0kw78qsNn3HQ. All subjects performed nine repetitions of each movement: three repetitions from the anterior, or front, camera view; three repetitions from the left lateral camera view; and three repetitions from the right lateral camera view. The order of the five test movements was not varied and followed the existing instruction and scoring documents (Kritz, 2012).

The protocol for capturing the MCS videos was established and tested during our pilot study (Dewhirst et al., 2015). The primary investigator supervised the equipment setup for all video recording sessions. At the beginning of each testing session, each camera was tested to ensure correct function and recording. Video cameras were started and stopped by volunteer physical therapy students from UVM who were instructed to check that each camera was recording and storing throughout the testing session. Videos were stored on a secured server at UVM, which is backed up daily and is password protected. Videos were evaluated by the primary investigator at a later date.

3.6.2 MCS test movements.

3.6.2.1 Body weight squat.

Perform a body weight squat with your fingertips on the side of your head and elbows out to the side. Squat as low as you comfortably can. Repeat the squat three times facing the camera, three times with your left side to the camera, and three times with your right side to the camera.

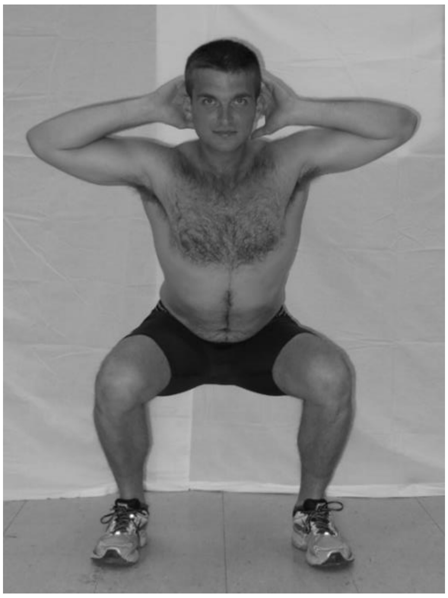

Figure 3.2. Body weight squat.

3.6.2.2 Lunge and twist.

Cross your arms and place your hands on your shoulders with your elbows pointing straight ahead. Perform a forward lunge as low as you can, then rotate towards the forward knee. Try not to touch trailing knee to the ground. Just rotate towards the knee then return to centre, and return to the standing position. Alternate legs with each repetition when facing the camera for a total of six repetitions. Then turn your left side to face the camera, and repeat the lunge and twist three times leading with your left leg. Finally, turn your right side to face the camera, and repeat the lunge and twist three times leading with your right leg.

Figure 3.3. Lunge and twist.

3.6.2.3 Push-up.

Perform a standard push-up. Go as low as you comfortably can. Repeat the push-up three times with your head towards the camera, three times with your left side to the camera, and three times with your right side to the camera.

Figure 3.4. Push-up.

3.6.2.4 Bend and pull.

Start with your arms stretched overhead. Bend forward allowing your arms to drop under your trunk. Pull your hands into your body as if you were holding on to a bar and performing a barbell rowing exercise. Return to the start position with your arms stretched overhead. Repeat the bend and pull three times facing the camera, three times with your left side to the camera, and three times with your right side to the camera.

Figure 3.5. Bend and pull.

3.6.2.5 Single leg squat.

Perform a single leg body weight squat with your fingertips on the side of your head, elbows out to the side, and the nonstance leg positioned behind the body. Squat as low as you comfortably can. Repeat the single leg squat on your left leg three times facing the camera, three times on your right leg facing the camera, three times on your left leg with your left side to the camera, and finally three times on your right leg with your right side to the camera.

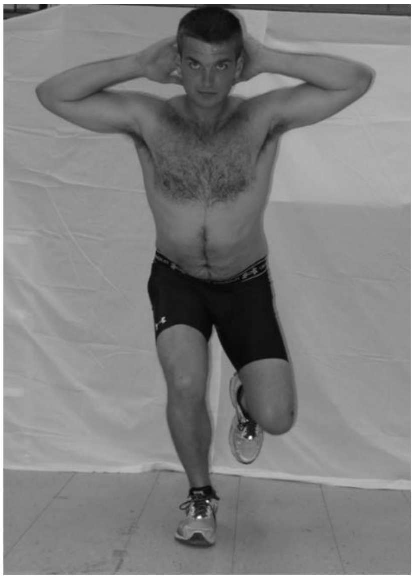

Figure 3.6. Single leg squat.

3.6.3 MCS video analysis.

All videos of all movement patterns for all subjects were analysed by the primary investigator using the MCS protocol previously established by Kritz (2012) (Appendix 7.6). Total score, individual movement scores, and observed movement impairments were recorded for each video (Appendix 7.7 scoring criteria and recording sheet, and Appendix 7.11 example data entry file). Videos were initially analysed within two weeks of the subjects enrolling in the study.

Individual movement evaluation and scoring was based on the original scoring criteria developed by Krtiz (2012), using a 0–3 scale where:

1 = two or more primary and and/or four secondary movement faults were observed

2 = one primary and/or zero to three secondary movement faults were observed

3 = zero primary and/or zero to two secondary movement faults were observed

An individual movement score of 1 indicates poor movement that requires attenuation of the body weight for the movement to be performed correctly, a score of 2 indicates a movement that can be performed correctly with body weight resistance, and a score of 3 indicates competent movement that can be challenged with external resistance such as free weights (Kritz, 2012). While there are only five movement patterns described in the MCS, the two compound movements (bend and pull, and lunge and twist) are divided in two for evaluation and scoring purposes, creating a total of seven movements, and therefore a maximum total score of 21. A total score of 10/21 or less is considered poor overall movement competency, 11–16/21 is considered moderate movement competency, and scores of 17/21 or greater are considered good movement competency (Kritz, 2012).

3.6.4 Intratester reliability of MCS scoring substudy.

Given the primary investigator of this study assessed all MCS screening tests, it was important to establish her intrarater reliability. Assuming alpha = .05, ICC of .80, CI with +/- .10, 1 sided CI, it was determined that a random selection of 37 videos should be rated a second time. The intratester reliability study was completed one month after the five-month enrolment period closed. Thus, the time between first and second viewing of the videos was between one and five months.

The degree of intrarater reliability was determined using the average measures intraclass correlation coefficient and found to be .87 (CI .75–.93). Using single measures intraclass correlation, the coefficient was found to be .77 (CI .59–.87, $p = .05$). Intrarater and interrater reliability of the total MCS score has been studied and reported as good elsewhere (Reid et al., 2015).

3.7 Hamstring Length and Trunk Muscle Endurance Testing

Hamstring length and trunk muscle endurance were recorded once for each subject at the time they enrolled in the study. The time commitment for the subjects, as well as the timeline for this master's thesis, did not allow follow-up measures at any other point during the study. Subjects completed one trial of the three muscle tests: (a) active straight leg raise hamstring length test left and right, (b) Biering-Sorensen back extensor muscle endurance test, and (c) McGill trunk flexor muscle endurance test. These particular tests were chosen to replicate the methodology, and thus ensure the useful comparison of the current data with two previously conducted studies of movement patterns and injuries in rowers (Newlands, 2013) and dancers (Lee, 2015). Verbal, pictorial, and demonstration instructions were given prior to each test. Measures were entered into an Excel spreadsheet (Appendix 7.10). Total time in minutes and seconds for the trunk endurance tests was converted to total time in seconds and then standardised as described below.

3.7.1 Active straight leg raise (ASLR).

This test was used to measure hamstring muscle length. The test was modified from previously published research (Cook et al., 2006b). The modified test described here is consistent with the method used in an earlier study and being replicated by this study (Newlands, 2013). Subjects were positioned supine on a plinth with the lumbar spine in a neutral position. The tester held a Universal Inclinometer (OPTP, 3800 Annapolis Lane North, Suite 165 - P.O. Box 47009, Minneapolis, MN 55447-0009, USA) at the lateral malleolus parallel with the long axis of the fibula. Subjects were instructed to actively raise their test leg as far off the plinth as possible while keeping the test knee extended. The tester maintained the inclinometer at the distal fibula, and also palpated the lumbar spine while the leg was moving. The subject was instructed to hold the test leg stationary at the point where the lumbar spine began to flex. This position was held for approximately five seconds while the angle of hip flexion was recorded from the inclinometer. Degrees of hip flexion for left and right legs were recorded. The accepted norm for hamstring length is 80^{o} of hip flexion ROM measured with a goniometer or inclinometer (Biering-Sorensen, 1984; Kendall, McCreary, Provance, Rodgers, & Romani, 2005).

The ability to perform the ASLR test requires functional hamstring flexibility, which is the flexibility that is available during physical activity (Cook et al., 2006b). This is different from passive flexibility, which is more commonly assessed. The subject must also demonstrate adequate hip mobility of the opposite leg and lower abdominal stability (Cook et al., 2006b). Poor performance during this test can be the result of insufficient passive hamstring length, poor functional hamstring flexibility, or inadequate mobility of the opposite hip to achieve the start position due to shortness or stiffness of the iliopsoas muscles (Cook et al., 2006b).

Figure 3.7. Active Straight Leg Raise Test, used to measure hamstring muscle length.

3.7.2 Biering-Sorenson trunk extensor muscle endurance test.

This test was used to measure the isometric endurance of the trunk extensor muscles as a group, and has been previously reported to be a reliable measure of back extensor muscle endurance (McGill, Childs, & Liebenson, 1999). To normalise the testing position for all subjects, the test was modified from the originally described test (Biering-Sorensen, 1984). The modified test described here is consistent with the method used in an earlier study and being replicated by this study (Newlands, 2013). The subjects were positioned in prone on a plinth with the upper body cantilevered off the end of the plinth (Figure 3.8). Two assistants were used to stabilise the subjects, one over the lower leg and one over the thighs. To begin the test, subjects crossed their arms over their chest and raised their trunk until it was horizontal to the floor. The horizontal position was held as long as possible. The test was stopped when the subject reached the predetermined maximum hold time for the test (180 seconds), failed to maintain the trunk parallel with the floor, chose to stop the test, or reported pain from the test position. The predetermined maximum hold time was set following a review of the literature during which it was established that there is variability in the reported maximum time. The original publication by Biering-Sorensen (1984) states that a hold time less than 176 seconds is predictive of an episode of low back pain in the next 12 months, while a hold time greater than 198 seconds predicted absence of low back pain in a group (n = 920) of 30–60-year-old residents of a suburb of Copenhagen, Denmark, but does not state a maximum hold time for future use of the test. In a critical appraisal of the literature reporting the Biering-Sorenson test, Demoulin, Vanderthommen, Duysens, and Crielaard (2006) reported that in patients who experience no difficulty in holding the position, the test is stopped after 240 seconds. In the primary investigator's clinical and academic teaching experience the Biering-Sorenson test is rarely held greater than 180 seconds, even in a group of highly motivated and competitive physical therapy students. The subjects in this study were stopped at 180 seconds, although two subjects requested to hold longer for their own challenge and were timed at 185 and 200 seconds. The endurance time from assuming the horizontal position until the trunk dropped below the horizontal was manually recorded in minutes and seconds using a stopwatch. Chan (2005) reported the reliability of this test to be excellent in a group (n = 5) of rowers tested two days and one week apart (ICC = .88). One verbal warning was given if the subject dropped below the horizontal.

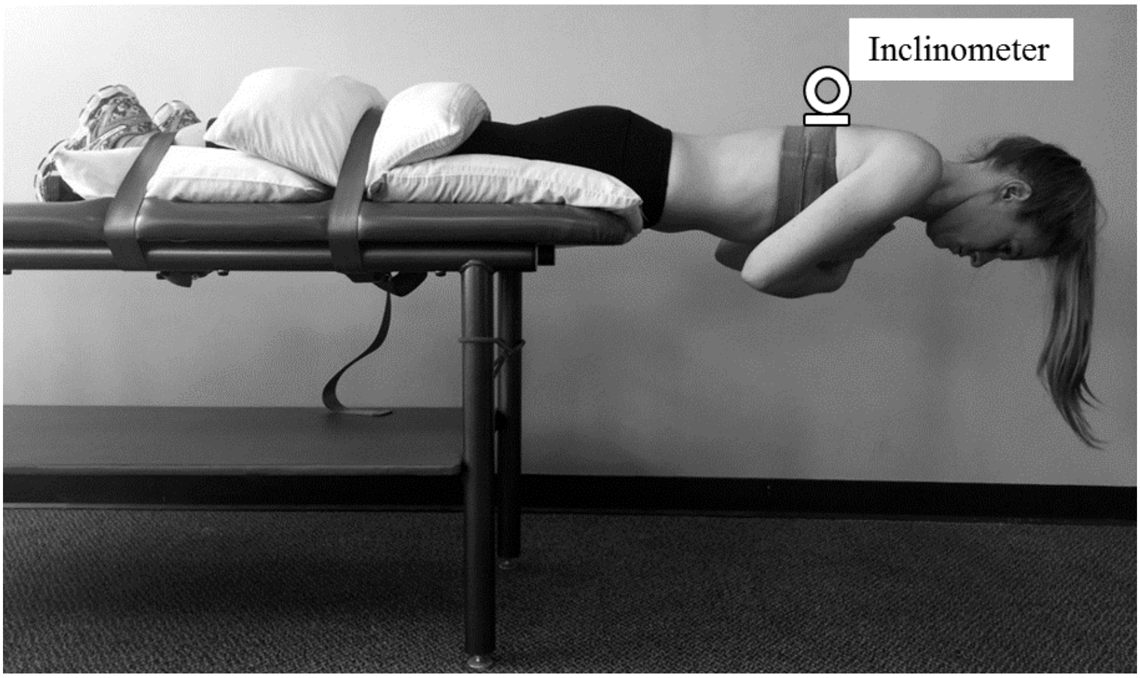

Figure 3.8. Modified Biering-Sorenson trunk extensor muscle endurance test.

3.7.3 McGill trunk flexor muscle endurance test.

This test measured the isometric endurance of the trunk flexor muscles as a group. Subjects lay on a plinth with both knees flexed to 90° and the arms folded across the chest. The original test stabilisation was modified because not all testing sites had straps or dumbbell weights to stabilise the feet. To normalise the testing for all subjects, an assistant stabilised the subject's feet. When subjects were ready, a second assistant helped the subject to raise the trunk off the plinth to a 55° angle. The angle was measured using a Baseline HiRes goniometer (OPTP, 3800 Annapolis Lane North, Suite 165 - P.O. Box 47009, Minneapolis, MN 55447-0009, USA). The moving arm of the goniometer was previously taped at 55°. The stationary arm of the goniometer was aligned parallel with the surface of the plinth, and the moving arm was aligned with the midaxillary line of the subject's trunk. Subjects maintained the trunk straight and the hips flexed at this angle as long as possible. The test was stopped when the subject reached the predetermined maximum hold time for the test (360 seconds), or failed to maintain the trunk at the 55° angle from the plinth, or chose to stop the test, or reported pain from the test position. The endurance time from assuming the test position until the angle increased or decreased from 55° was manually recorded in minutes and seconds using a stopwatch. Chan (2005) reported the reliability of this test to be excellent in a group (*n* = 5) of rowers tested two days and one week apart (ICC = .93). One verbal warning was given if the subject increased or decreased their trunk angle.

Figure 3.9. McGill trunk flexor muscle endurance test.

3.7.4 Trunk muscle endurance ratio calculation.

The trunk muscle endurance ratio (core ratio) was calculated as flexor to extensor ratio using each subject's standardised scores. The trunk muscle endurance ratio (core ratio) described here is consistent with the method used in an earlier study and being replicated by this study (Newlands, 2013). For each subject, the McGill trunk flexor muscle endurance test time was standardised to 360 seconds and the Biering-Sorenson trunk extensor muscle endurance time was standardised to 180 seconds before calculating ratios. Trunk muscle endurance ratio was calculated for comparison to previously published mean ratios (calculated using the same method as just described) for men (0.99) and women (0.79) (McGill et al., 1999).

3.8 Statistical Analyses

3.8.1 Survey response data processing.

The survey responses were exported from REDCap for statistical analysis. Previous as well as new injuries were grouped by body region: (a) lower extremity, which included hip, thigh, knee, lower leg, foot, and ankle; (b) upper extremity, which included shoulder, upper arm, elbow, forearm, wrist, and hand; and (c) trunk, which included head, neck, upper back, low back, and pelvis. Low back pain and acute/traumatic and nontraumatic/overuse injuries were included in the appropriate group, and also reported separately, due to current interest in these categories from the global sporting community. Free text survey responses were analysed by hand for common themes. Injuries reported in the “other” category (used when subjects did not feel the location of their injury was adequately described by any of the anatomic body part choices) were classified after subjective analysis of the associated free text field that asked for description of the injury.

3.8.1.1 Calculation of injury incidence.

Injury incidence was calculated as number of new injury reports per subject, per 1,000 hours of training/exposure, as recommended by Fuller et al. (2006). Throughout this study, a new injury includes any episode of pain, ache, or discomfort that lasted for longer than one week (seven days), or caused the athlete to miss or modify any training or racing sessions (Newlands, 2013). Differentiating between a new injury, and a new episode of a previous injury, was beyond the scope of the questionnaire designed for this study.

3.8.1.2 Calculation of training/exposure hours.

For each training activity (e.g., roller skiing, running, skiing, cycling), subjects reported the number of training sessions per week, and the average duration of each training session (rounded to the nearest whole hour). Training hours per subject were calculated by multiplying the number of training sessions by the average duration of each training session for that activity per week, and per month. Total training/exposure hours, or specific activity hours, could then be summed per subject.

3.8.1.3 Calculation of training time and racing time lost due to injury.

The total potential available training sessions were determined from the sum of the number of training sessions, number of training sessions modified due to injury, and the number of sessions lost to injury. The total races scheduled were determined from the sum of the number of races completed, number of races modified due to injury, and the number of races lost to injury. Thus, training time modified or lost due to injury is expressed as a fraction of total potential available training sessions. Racing time modified or lost is expressed the same way. Injury, training, and racing data collection were not structured for more elaborate statistical exposure, or statistical risk analyses, as these were not included in the study purpose or hypotheses.

3.8.2 Primary hypothesis testing.

A *t*-test was used to compare the MCS score between injured and noninjured subjects. We also performed a Spearman's correlation to determine the correlation between MCS score and new injury report during the 12 months of the study.

3.8.3 Secondary hypothesis testing.

Our secondary hypotheses were that new injury will be associated with (a) a history of injury, (b) a long career in cross-country skiing, (c) high training hours, (d) high running training hours, (e) high roller ski training hours, (f) poor trunk muscle endurance, and (g) reduced ASLR. To test these hypotheses Spearman's correlations were calculated for these variables compared to new injuries during the 12 months of the study.

3.8.4 Risk factors for new injury.

To determine if we could predict new injury from any demographic data, intake physical measures, or monthly injury, training ,and racing data, we developed a regression model. The variables of age, BMI, gender, number of years of competition, age began competing, past injury report, trunk muscle endurance ratio, hamstring length, MCS score, average monthly time training, average monthly time running, average monthly time roller skiing, average monthly time cycling, average monthly time skiing, and average monthly time lifting weights were all inserted into Spearman's correlation calculations comparing them to new injuries. The variables with statistically significant correlation coefficients, or that were considered clinically important to new injuries, were included in the final regression model. Clinical importance was determined from the primary investigator's clinical experience, examination of the literature, discussion with coaches during the study development phase, and discussion with researchers conducting similar studies in different sporting populations.

3.8.5 Regression model construction.

The independent sets of data from each subject were used to determine the relationship between possible risk factors and the likelihood of a new injury during the study period, and a regression analysis was performed.

3.8.5.1 Generalised linear model.

A generalised linear model was used to predict new injuries. The total number of new injuries was aggregated over all survey months for each subject. Given that the aggregation is a count of the number of occurrences of new injuries, the data will not be normally distributed and a generalised linear model that assumes a negative binomial distribution was used because the Pearson Chi Square/degrees of freedom statistic indicated a better fit than Poisson. Variables considered for inclusion in the model included: age, gender, BMI, age began competing in cross-country skiing, years of cross-country ski competition, past injuries, MCS score, hamstring length, core ratio, average monthly time training, average monthly time running, average monthly time cycling, average monthly time on roller skis, and average monthly time weight training. Variables were used in the final model if they significantly correlated with new injury reports ($p < .05$), were considered clinically important by the primary investigator based on clinical experience and review of literature, or had been included by investigators who used a similar research methodology (Lee, 2015; Newlands, 2013). The variables used in the final model were: past injury, total training hours, running hours, and MCS score.

Logistic regression was attempted, but all models failed to converge due to low injury numbers and lack of variability in the data.

3.9 Additional Data Analyses

This study also aimed to describe the characteristics of a group of NCAA and professional cross-country skiers in the northeastern USA. Demographic data were used to describe the subjects in the study population. Means and standard deviations were calculated for continuous variables: age, BMI, number of years of competition, age began competing, trunk muscle endurance ratio, hamstring length, and MCS score. Frequencies were calculated for categorical variables: gender, past history of injury, injured at time of enrolment, location of injury, and type of injury (traumatic or not). *T*-tests were used to determine any gender differences in the demographic and intake physical measurement data. While this study was not powered to detect gender differences, we explored these differences when describing the characteristics of the subjects.

This study also aimed to report injury incidence in a group of NCAA and professional cross-country skiers in the northeastern USA. Injury incidence was calculated as mean injury incidence per subject per 1,000 hours of training. To determine if injury incidence was different between the ski season and off-season, acute/traumatic and nontraumatic/overuse injuries, and injuries by body region, a paired *t*-test was used to compare mean injury incidence per subject per 1,000 hours of training. Although this study was not powered to detect these differences, we explored these differences during analysis of injury incidence in the related literature.

4 Results

This chapter presents the study results. Section 4.1 describes the subjects in this study by presenting the analyses of the demographic and physical test data for all subjects who enrolled in the study (n = 71 subjects). Section 4.2 presents the analyses of the data from the 41 subjects who completed the 12-month study. The section continues on to analyse the primary hypothesis, which includes examining the monthly survey responses (new injuries, training and racing loads, and injury incidence) and the relation of these variables to the initial MCS score. Section 4.2 continues on to present the relationships between intake data, training type, training amount, and new injuries and presents the results of the regression analysis as well as the prediction of risk factors for experiencing a new injury.

4.1 Intake Demographic and Intake Physical Measurement Analyses

This section presents the characteristics of the group of cross-country skiers who enrolled in this study. The demographic information collected from each subject includes: age, height, weight, BMI, age began competing, years of competitive skiing, past injury history, and injury status on the day of enrolment. The physical measurements collected on day of study enrolment included MCS score, hamstring length, trunk flexor endurance time, trunk extensor endurance time, and trunk endurance ratio that was calculated from the normalised trunk flexor endurance and trunk extensor endurance times. Gender comparisons are also presented for each demographic and physical measurement variable.

4.1.1 Subjects.

This section addresses one of the main aims of this study, which was to describe the characteristics of a group of NCAA and professional cross-country skiers in the northeastern USA, including any differences in the characteristics of the men and women. The demographics of the participating subjects, their skiing and injury history, and their MCS scores, hamstring length, and trunk muscle endurance test scores are presented in this section.

4.1.1.1 Demographics.

A convenience sample of 71 subjects volunteered for this study (35 men and 36 women, age range 18–27 years). Subjects were enrolled from two professional ski teams, three Vermont NCAA cross-country ski teams, and one Maine NCAA cross-country ski team. Recruitment aimed to enrol as many subjects as possible up to 88, to ensure 70 subjects were retained throughout the 12 months of the study. Due to subject availability and enrolment time constraints, 71 subjects enrolled in the study, and 41 subjects completed the study through the 12-month follow-up period. Factors that limited the enrolment to 71 were: proximity of, and ease of, testing-eligible, willing cross-country skiers, and the desire to study only one competitive ski season for this baseline data collection. One professional team from eastern Maine was unable to participate due to their location being an eight-hour drive from the primary investigator's state of residence. Two ski high schools were unable to participate as their potential subjects did not meet the minimum age requirement. One professional ski team did not respond to e-mail requests for an informational meeting with the primary investigator. Three NCAA teams were unable to participate as their institutional policies restrict their students from participating in research studies at other institutions. The greatest dropout occurred after the month one enrolment and before the month three survey when 22 subjects were lost to follow-up. A further five subjects were lost in the final two months of the study. Three subjects were lost to follow-up between month three and month 10 of their participation. Two subjects formally withdrew from the study within the first three months of participation, one subject developed a long-term systemic illness, and the other subject underwent hip joint surgery. This resulted in 41 subjects being retained for longitudinal analysis.

Table 4.1 summarises the demographics of the subjects at the time of enrolment in the study. As expected, the men were significantly taller and heavier than the women, but there was no significant difference between men and women for the other demographic variables.

Table 4.1. Subject Demographics at Enrolment

Variable	**Men (SD)** ***n* = 35**	**Women (SD)** ***n* = 36**	***p*-value**
Mean age (years)	21.15 (2.48)	20.18 (1.92)	.07
Mean height (cm)	177.87 (6.82)	168.46 (6.69)	< .05*
Mean weight (kg)	71.14 (7.26)	62.32 (7.06)	< .05*
Mean BMI	22.45 (1.41)	21.93 (1.74)	.17
Mean age began competitive skiing (years)	11.6 (2.90)	12.0 (2.74)	.55
Mean years skiing	11.4 (5.04)	11.1 (5.45)	.85
Number of subjects with past history of injury	80%, 28/35	80.6%, 29/36	.95
Number of subjects injured at time of enrolment	25.7%, 9/35	27.8%, 10/36	.84

Note. SD = standard deviation. * = significant at $p = .05$.

4.1.1.2 History of injuries.

Of all the past injuries, there were a greater number of lower-extremity injuries reported than other regions (Table 4.2). At least one previous episode of injury was reported by 80% of subjects (28 men, 29 women). Although a similar number of men and women reported prior injuries, the type of injuries was different between genders. Men reported a higher number of episodes of low back pain, and also a higher number of fractures.

Table 4.2. Number of Subjects Reporting Types of Previous Injuries at Enrolment (Qualitative Analysis From Free Text Survey Question "List Previous Injuries")

Type of previous injury	**Men (n = 28)**	**Women (n = 29)**
Any trunk injury	12	7
Low back pain	8	2
Head injury	2	2
Any upper-extremity injury	10	9
Any lower-extremity injury	21	23
Any fracture	10	5
Upper-extremity fracture	6	2
Lower-extremity fracture	5	3

Note. Many subjects reported multiple types of previous injuries. Only previous injuries from major body areas are reported here.

4.1.1.3 Movement Competency Screen (MCS) and muscular measures.

MCS, hamstring muscle length, and trunk muscle endurance test results are summarised in Table 4.3 and explained in the subsections that follow.

Table 4.3. MCS and Muscular Measures Scores, All Subjects at Enrolment

Mean MCS and muscular score	**Men (SD)**	**Women (SD)**	***p*-value**
N	35	36	
MCS score	14.43 (1.46)	12.58 (1.40)	< .05*
Right hamstring length (degrees)	73.69 (12.27)	75.53 (10.99)	.51
Left hamstring length (degrees)	72.66 (10.82)	76.11 (11.35)	.19
McGill trunk flexor endurance time (seconds)	227.00 (107.24)	226.42 (112.18)	.98
Biering-Sorenson trunk extensor endurance time (seconds)	123.91 (28.11)	133.51 (33.95)	.13
Trunk muscle endurance ratio (flexor/extensor)	0.97 (0.55)	0.85 (0.40)	.25

Note. SD = standard deviation. * = significant at $p = .05$.

4.1.1.3.1 MCS video analysis.

The range of MCS scores across all subjects was 10/21 to 18/21, with a median score of 13/21. MCS scores were significantly higher for men than women ($p < .05$) (Table 4.3, Figure 4.1). When categorising the MCS scores, three men achieved a “good” rating (>/= 17/21), two women were rated as “poor” movers (</= 10/21), and the remaining subjects were rated as “moderate” movers on the MCS (Figure 4.1). When observing the individual movements of the MCS, men scored higher than women on the push-up and the twist movements (Table 4.4).

Table 4.4. Mean Scores for Individual MCS Movements, All Subjects at Enrolment

	Double leg Squat	Lunge	Twist	Push-up	Bend	Pull	Single leg Squat
All subjects	2	2	1	2	2	3	1
Men	2	2	2	3	2	3	1
Women	2	2	1	2	2	3	1

Subjects who were injured at the time of MCS testing did not have significantly different MCS scores than the noninjured subjects (p = .79) (Figure 4.1, Table 4.5).

Table 4.5. Mean MCS Scores for Injured and Noninjured Subjects at Enrolment

	Injured (SD)	Not injured (SD)	*p*-value
All subjects	13.58 (1.54) *n* = 19	13.46 (1.77) *n* = 52	.79
Men	14.33 (1.12) *n* = 9	14.46 (1.58) *n* = 26	.22
Women	12.90 (1.60) *n* = 10	12.46 (1.33) *n* = 26	.41

Note. SD = standard deviation.

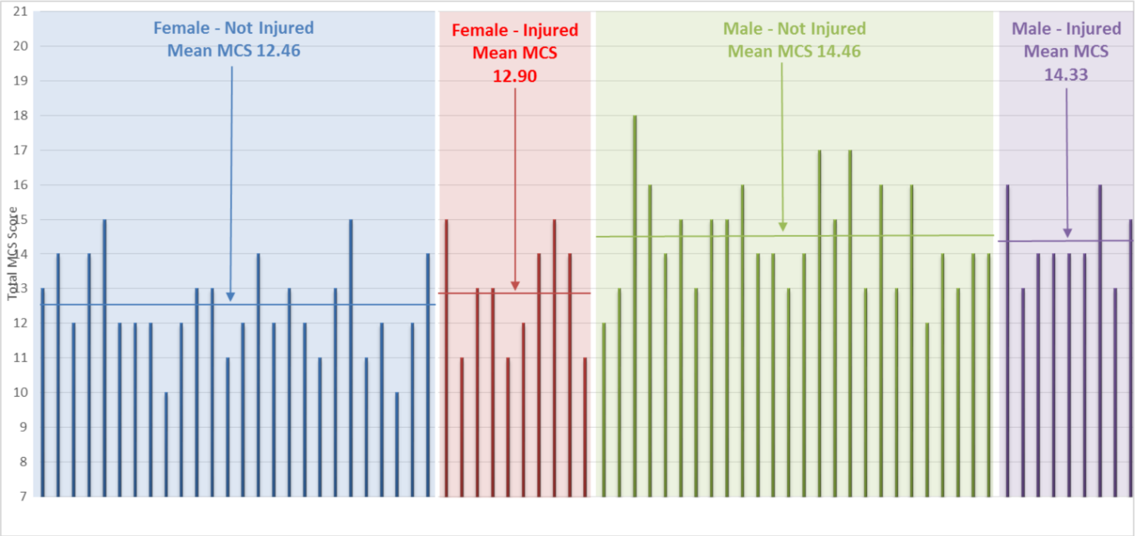

Figure 4.1. Total MCS scores by subject, gender, and injury status at enrolment.

4.1.1.3.2 Hamstring muscle length.

The range of hamstring muscle length for all subjects was: 44° of hip flexion (very short) to 95° of hip flexion (excessive length) (Kendall et al., 2005). There was no significant difference in mean hamstring length between men and women (Table 4.3).

4.1.1.3.3 Trunk muscle endurance testing.

Biering-Sorenson test of back extensor muscle endurance scores ranged from 66 to 180 seconds. McGill trunk flexor endurance test scores ranged from 32 to 360 seconds. There was no significant difference in mean trunk endurance times between men and women. Trunk muscle endurance ratio of the normalised trunk flexor to extensor muscle endurance scores ranged from 0.18–2.73. There was no significant difference in mean trunk muscle endurance ratio scores between men and women (Table 4.3). Two subjects were not scored as they did not complete the Biering-Sorenson test due to low back pain on the day of testing.

4.2 Longitudinal Analyses of Training Load and New Injuries From Monthly Survey Responses

This second section of the results chapter uses the data from the 41 subjects who completed the 12-month study. First a summary of the intake variables for these 41 subjects is presented. This section then presents (a) the survey response rate; (b) the new injuries and the body part injured; (c) the amount and type of training; (d) the injury incidence found in this study; (e) training sessions and races lost or modified due to injury; (f) the relationship between new injuries and subject demographics, MCS scores, core endurance ratio scores, hamstring length, training load, and time of year; and (g) the results of risk factor prediction from regression analysis between new musculoskeletal injury and possible risk factors.

4.2.1 Intake variables for the 41 subjects retained in longitudinal analysis.

Subjects completing the study were 23 females and 18 males. Previous injury status, mean MCS scores, hamstring length, and trunk muscle endurance ratios for these 41 subjects are shown in Table 4.6. Of the 41 subjects who completed the study, 13 males and 14 females became injured during the study. The females who became injured had significantly shorter right and left hamstring muscles, and a lower trunk muscle endurance ratio than the uninjured females. The males who became injured had significantly longer left hamstring muscles, and a lower MCS score than the uninjured males. Hamstring length may play a different role in injury risk for male than female cross-country skiers. MCS score may be a useful injury predictor in male cross-country skiers. Trunk muscle endurance ratio may be a useful injury predictor in female cross-country skiers. However, the small number of injuries reported, and the number of subjects in each gender and injury status category, are too small for further analysis. Two females and one male became injured for the first time in their career during this study. Four females and no males remained uninjured in their career at the end of this study.

Table 4.6. Intake Demographics for the 41 Subjects Who Completed the Study

MCS, muscular measures and previous and new injury data	**All subjects (SD)** ***N* = 41**	**Men (SD)** ***n* = 18**	**Women (SD)** ***n* = 23**
Number of subjects previously injured	34/41	17/18	17/23
Number of subjects not previously injured	7/41	1/18	6/23
Number of subjects newly injured	27/41	13/18	14/23
Number of subjects noninjured	14/41	5/18	9/23
Mean MCS score newly injured	13.15 (1.27)	13.69	12.64
Mean MCS score noninjured	13.43 (1.68)	15.00	12.56
***p*-value**	.56	.04*	.88
Mean hamstring length newly injured	R = 72 (10)	R = 75 (8)	R = 69 (11)
	L = 72 (10)	L = 75 (7)	L = 69 (11)
Mean hamstring length noninjured	R = 74 (11)	R = 73 (10)	R = 75 (11)
	L = 73 (11)	L = 71 (10)	L = 81 (11)
***p*-value**	R = .10	R = .33	R = .00*
	L = .48	L = .02*	L = .00*
Mean trunk muscle endurance ratio newly injured	0.90 (0.53)	1.13 (0.64)	0.70 (0.29)
Mean trunk muscle endurance ratio noninjured	0.86 (0.45)	0.91 (0.58)	0.83 (0.32)
***p*-value**	.83	.13	.02*

Note. * = statistically significant $p < .05$.

4.2.2 Survey analysis.

4.2.2.1 Survey response rate.

Twenty-three females, and 18 males, for a total of 41 subjects (57.7%), completed nine or more of the 12 monthly surveys, not necessarily sequentially (Table 4.7). The responses from only these 41 subjects were used: (a) to report new injuries; (b) in the analysis of injury incidence; (c) to report training load, and; (d) to determine the relationship between new injuries and the intake data, the MCS score, the hamstring length, the trunk muscle endurance test results, the type of training, and the duration of training.

Table 4.7. Number of Subjects Who Completed Surveys, by Study Month

Month of study	Number of subjects who completed the monthly survey
1	71
2	55
3	49
4	42
5	44
6	42
7	40
8	39
9	41
10	40
11	34
12	36

4.2.2.2 Injuries reported.

A total of 90 new injuries were reported during the study period by 27 of the 41 subjects whose data were retained for longitudinal analysis. New injuries were grouped into body regions: trunk (n = 12), upper extremity (n = 19), and lower extremity (n = 58) (Figure 4.2). New injuries reported in the "other" category (n = 5) were classified after analysis of the associated free text field that asked for description of the injury: two of these new injuries were concussion injuries (included in trunk group), one was a chest contusion (trunk group), one was shins and calves (lower-leg category, and therefore, lower-extremity group), and the final report was a viral infection to an eye (uncategorised). More injuries were reported for the lower extremity than any other region. Men reported a near even distribution of upper and lower-extremity injuries, whereas women reported more lower than upper-extremity injuries (Figure 4.2).

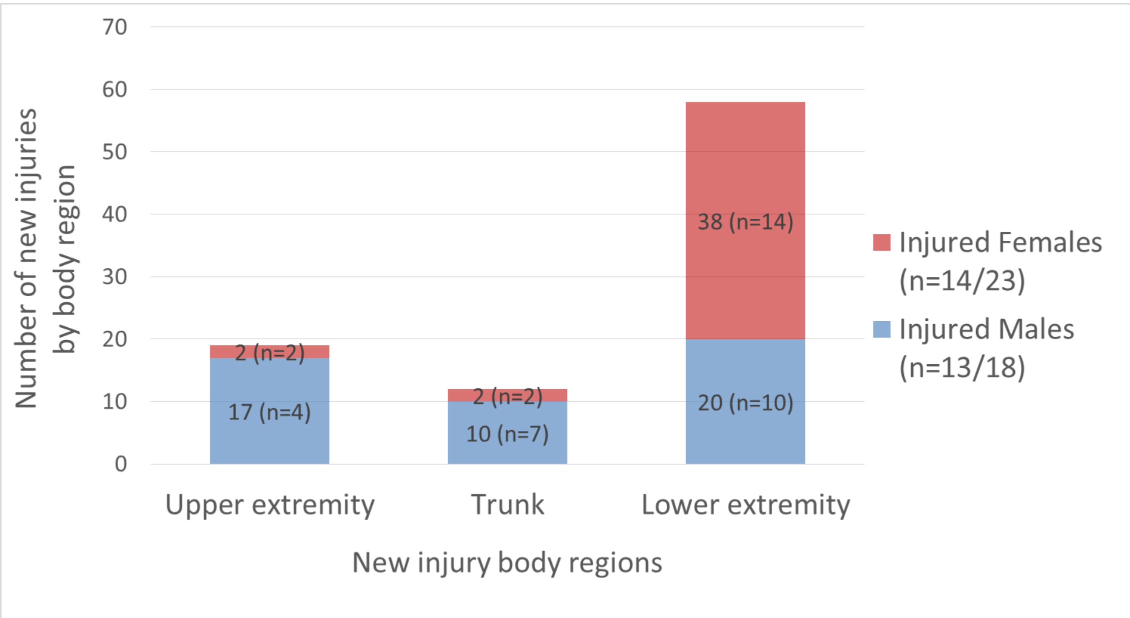

Figure 4.2. Number of new injuries by body region and by gender. Numbers in bars show number of new injuries; numbers in parentheses show number of subjects reporting the new injuries.

Figure 4.3 shows the new injuries divided into anatomic locations. Ankle and foot injuries accounted for 39.7% of all lower-extremity injuries, and 25.6% of all the new injuries. Shoulder injuries accounted for 36.8% of all upper-extremity injuries, but only 7.8% of all the new injuries.

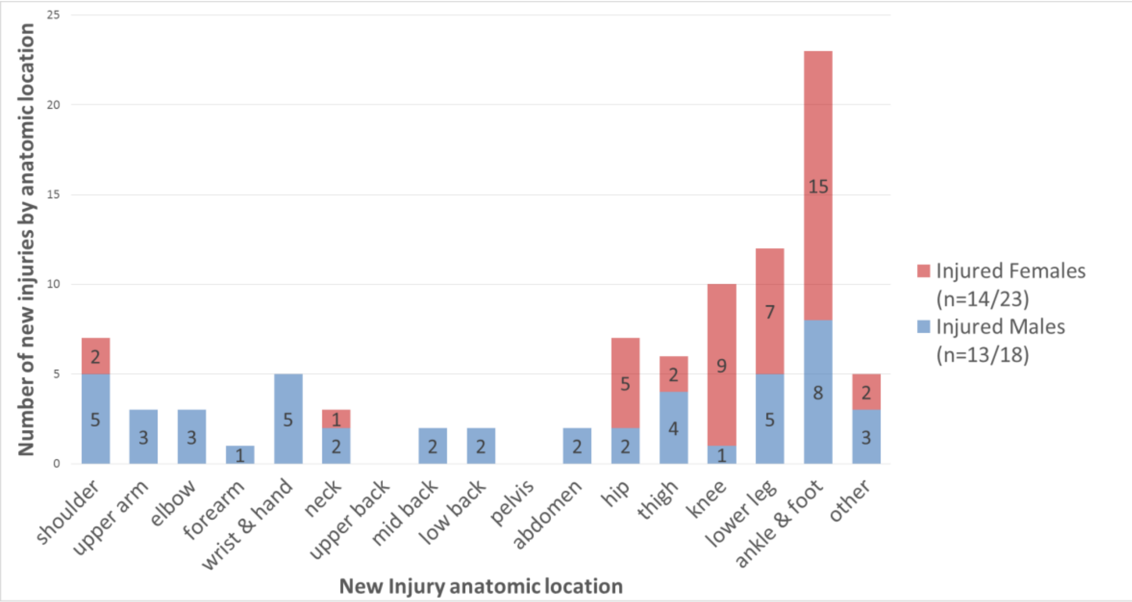

Figure 4.3. *Number of new injuries by anatomic location and gender (numbers in bars show number of injuries by gender).*

Female cross-country skiers were more susceptible to knee, ankle, and foot injuries than their male counterparts, while male cross-country skiers were more susceptible to upper-extremity injuries than their female counterparts.

Of the 90 new injuries reported during the study, 26 were reported as the result of a traumatic event. During the off-season (August to November 2014, and May to November 2015) 67 new injuries were reported compared to 23 new injuries during the ski season (December 2014–April 2015).

4.2.2.3 Training reported.

For the 41 subjects retained for the longitudinal analyses, a total of 24,904 training hours were reported during the study including: 7,384 hours of skiing, 7,168 hours of running, 4,740 hours of roller skiing, and 2,719 hours of cycling (Figure 4.4).

Although the type of training activity is different per season, there was no significant difference in mean monthly training time between ski season (52.56 hours per subject, per month) and off-season (55.60 hours per subject, per month) ($p = .25$) (Figure 4.5 in injury incidence section). Mean training hours for August and September 2014 are larger because only a small number of subjects were enrolled, and these subjects happened to be predominantly professional skiers who dedicate more time per month to training than the NCAA skiers. The NCAA subjects were enrolled between mid-September and mid-December 2014. Data from August 2015 to December 2015 does not include the professional skiers (their 12-month commitment to the study was August 2014 to July 2015). Figure 4.4 shows the training activities used each month. Roller skiing is reported during the off-season; skiing is reported during the ski season. A small number of subjects reported skiing outside ski season due to international travel or access to artificial snow. The time spent cycling and running is greater during the off-season, although some running was performed in every month of the study.

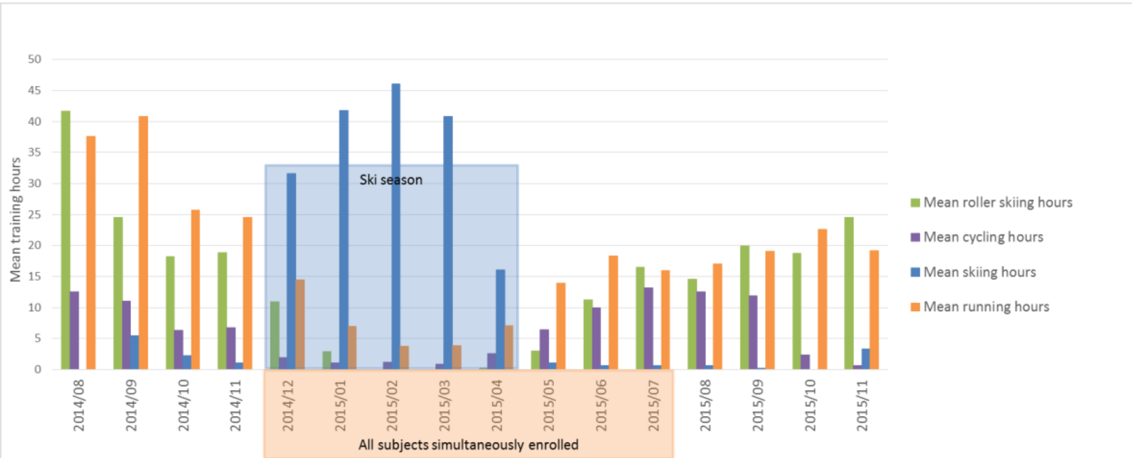

Figure 4.4. Mean training hours per subject, per month, by activity.

4.2.2.4 Injury incidence.

This study aimed to report the injury incidence in a group of NCAA and professional cross-country skiers in the northeastern USA, and to determine if injury incidence was different between: (a) the ski season and off-season, (b) traumatic and nontraumatic injuries, and (c) injuries by body region; these findings are presented in Table 4.8. The mean injury incidence was 3.81 new injuries per subject per 1,000 hours of training. There was a significantly higher incidence of nontraumatic injuries than traumatic injuries (p = .02). There was a significantly higher incidence of lower-extremity injuries than any other body region (upper extremity, trunk, low back) (p < .05). The seasonal injury incidence data hints at a difference between the off-season (5.25) and the ski season (2.27), but the difference is not statistically significant (p = .07) (Table 4.8, Figure 4.5).

Table 4.8. Mean Injury Incidence per Subject per 1,000 Hours of Training

Type of injury	Injury incidence	Type of injury	Injury incidence	*p*-value
All injuries	3.81			
LE	2.13	**UE**	0.46	< .05*
LE	2.13	**Trunk**	0.22	< .05*
LE	2.13	**Low back**	0.08	< .05*
Overuse/nontraumatic	2.76	**Acute/traumatic**	1.05	< .05*
Off-season	5.25	**Ski season**	2.27	.07

Note. * = significant at p < .05. LE = lower extremity. UE = upper extremity.

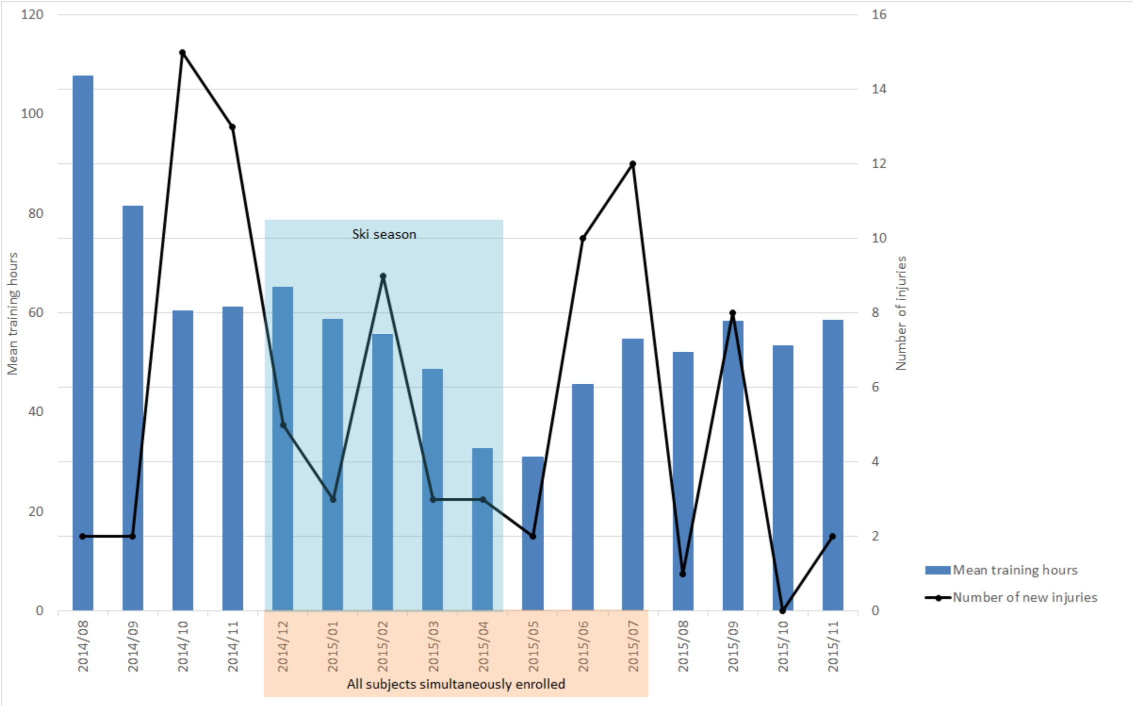

Figure 4.5. Number of injuries from all subjects, and mean training hours per subject, per month.

4.2.2.5 Training and racing lost to injury.

Total scheduled training sessions were the sum of number of training days, number of training days lost to injury, and number of training days modified due to injury, from all subjects. Total scheduled races throughout the study were calculated the same way. There were 14,800 training sessions, and 890 races scheduled during the study. Twenty-three subjects (56%) reported some training or racing days lost or modified. Percentages of lost or modified training sessions and races due to injury were small (Table 4.9 and Table 4.10). Due to such small percentages of training and racing loss, further analyses of exposure data were not considered.

Table 4.9. Training Sessions Lost or Modified Due to Injury (All Subjects)

Training sessions	% of sessions affected	Number of sessions affected
Lost or modified due to injury	3.83%	567/14,800
Lost to injury	1.17%	173/14,800
Modified due to injury	2.66%	394/14,800

Table 4.10. Races Lost or Modified Due to Injury (All Subjects)

Races	% of races affected	Number of races affected
Lost or modified to injury	4.27%	38/890
Lost to injury	2.48%	22/890
Modified due to injury	1.80%	16/890

4.2.3 Correlations with new injury—testing the primary and secondary hypotheses.

This section presents the relationships between new injury report and subject demographics, intake survey responses, MCS scores, muscular tests (hamstring length, trunk flexor muscle endurance, and trunk extensor muscle endurance), and monthly survey responses.

4.2.3.1 Primary hypothesis testing.

The primary hypothesis was that MCS score is related to new injury. MCS score did not correlate with new injury report in this study of cross-country skiers ($p = .63$). Nor was there a significant difference between MCS scores of injured and noninjured cross-country skiers ($p = .56$) (Table 4.6). When analysing by gender, the injured males had an MCS score significantly lower than the noninjured males ($p = .04$), but this was not true for the female subjects (Table 4.6).

4.2.3.2 Secondary hypothesis testing.

The secondary hypotheses were that new injury would correlate positively with the following variables: (a) a history of injury, (b) a long career in cross-country skiing, (c) high training hours, (d) high running training hours, (e) high roller ski training hours, (f) poor trunk muscle endurance, and (g) reduced ASLR. Table 4.11 shows the correlation coefficient and *p*-value for the variables expected to correlate with new injury reports. New injury was positively correlated with previous injury history ($p = .04$), thus supporting the secondary hypothesis: (a) history of injury can lead to new injury. New injury was not positively correlated with the remaining variables: (b) a long career in cross-country skiing, (c) high training hours, (d) high running training hours can lead to new injury, (e) high roller ski training hours, (f) poor trunk muscle endurance, and (g) reduced ASLR, and thus, those hypotheses were not supported by our results. The relationship between monthly run training hours and new injury may warrant inclusion in future studies based on the hint of a relationship in this study ($p = .08$). For full correlation output see Appendix 7.11.

Table 4.11. Variables Expected to Correlate With Total New Injuries

	Total new injuries	
Variable	**Spearman's Rho**	***p*-value**
Past injury	.32	.04*
Average monthly time running	.28	.08
MCS score	-.08	.63
Average monthly total training time	.17	.30

Note. * = significant at .05 level.

4.2.4 Prediction of risk factors for experiencing a new injury.

This section presents the results from the regression analysis between new injury and possible risk factors.

4.2.4.1 Generalised linear model.

To determine the relationship between possible risk factors and reporting a new injury during the study, a generalised linear model was constructed using the longitudinal data set from the 41 subjects who completed the study. New injury report was the dependent variable, and this was compared to: age, gender, BMI, years skiing, age began skiing, past injury report, MCS score, hamstring length, core muscle endurance ratio, monthly total training hours, monthly running hours, monthly cycling hours, monthly roller ski hours, and monthly ski hours. The final generalised linear model contained the following independent variables: past injury, monthly running time, monthly total training time, and MCS score. These variables were retained in the model for their statistical significance or their clinical relevance to new injuries. Table 4.12 shows that past injury report was a significant predictor of new injury when accounting for training time, run time, and MCS score in the model ($p < .05$).

Table 4.12. Generalised Linear Model

Variable	B	Std error	95% confidence interval		Wald Chi-Square	Sig.
			Lower	Upper		
Total training time	0.00	0.01	-0.02	0.03	0.01	.92
Total run time	0.08	0.12	-0.16	0.31	0.40	.53
Past injuries	1.34	0.67	0.03	2.66	4.02	< .05*
MCS score	-0.01	0.14	-0.28	0.27	0.00	.97

Note. * = significant at .05 level.

5 Discussion

5.1 Main Findings

The primary hypothesis of this study was that new injury is associated with poor movement competency in cross-country skiers. The secondary hypotheses were that new injury is associated with: (a) a history of injury, (b) a long career in cross-country skiing, (c) high training hours, (d) a high number of training hours spent running, (e) a high number of training hours spent roller skiing, (f) poor trunk muscle endurance, and (g) reduced ASLR. This study also aimed to report mean injury incidence per subject per 1,000 hours of training/exposure in cross-country skiers.

The results of the current study found no relationship between MCS score and new injury over a 12-month time period in elite cross-country skiers. However, the MCS scores have established baseline data about the movement competency of this group of elite cross-country skiers and can be compared to the MCS scores of other endurance athletes, thus enhancing our knowledge about movement competency in the endurance athlete population. The study did find that a past history of injury was positively correlated with new injury reports, thus supporting one of our secondary hypotheses. However, no other independent variable correlated with new injury reports. The low injury incidence reported in this group of elite cross-country skiers is comparable to previously published injury incidence in cross-country skiers and other endurance athletes.

5.1.1 Subjects.

Seventy-one subjects were recruited and enrolled in the study. The expected gender differences of males being heavier and taller than females prevailed. No other differences were seen in demographics between men and women. The age range, and other demographics, are consistent with other recently published cross-country ski injury studies (Bahr et al., 2004; Blut et al., 2010; Clarsen et al., 2014; Østerås et al., 2013; Ristolainen et al., 2014). The NCAA teams included in this study aim for equal numbers of men and women on their team rosters, and consequently men and women were equally represented in our study group (men n = 35, women n = 36).

5.1.2 History of injuries.

Eighty percent of our subjects had a history of injury with a greater number of lower-extremity injuries than any other body region. This is consistent with the current literature. Once the first injury has been sustained, the risk for future injuries rises (Ristolainen et al., 2014; Van Mechelen et al., 1996). The prevention of the initial injury is an important place to focus injury reduction and prevention resources. The large number of our subjects with a history of injury (80%) suggests the initial injury occurs during adolescence; thus, a focus on preventing adolescent injuries would be important for lifelong injury reduction. Additional information from the subjects about the nature of their previous injuries, the type of rehabilitation, whether the subject had completed a full return to training and racing, and the specific dates of the injury and the final return to racing would be of great value in future studies to investigate relationships between type of previous injury and subsequent injury. This would be a complex study requiring detailed medical record review for the prior injuries, or a longitudinal study with access to coaching and medical records over many years. Further research about the relationships between specific injuries and subsequent injuries, especially the overuse injuries sustained by cross-country skiers, is required.

5.1.3 MCS scores at enrolment.

The mean MCS scores of our cross-country skiers were comparable to those reported for rowers (Newlands, 2013), netballer players (Reid et al., 2015; Vanweerd, 2013), and dancers (Lee, 2015). No published reports of any whole body movement screen scores for elite cross-country skiers were found for comparison; thus, our data begins the collection of whole body movement screen information (specifically the MCS) in cross-country skiers. The only MCS data in cross-country skiers available for comparison are from a proof of methodology pilot study undertaken for this master's project, in which the MCS and FMS scores of 18 adolescent cross-country skiers were recorded. The MCS scores of the 18 adolescent cross-country skiers were 7–17/21 with a mean score of 11.4/21 (Dewhirst et al., 2015). The MCS scores of the elite cross-country skiers in our study are slightly higher than the scores from the pilot study, as expected from older, skeletally mature athletes who also have experience with gym-based weight training exercises similar to the movements of the MCS.

5.1.3.1 Interpretation of MCS scores.

Although the mean MCS score for men (14.4) in our study was significantly higher than for women (12.6) ($p < .05$), both these mean scores fall in the "moderate" movement category (11–16/21), and the majority of mean individual movement scores fall below level 3 (Figure 4.1, Table 4.3, and Table 4.4 in results chapter). An individual movement scored at level 3 is defined to be safe to train with external load, a level 2 movement is safe to train with body weight resistance, and a level 1 movement requires load attenuation for safe movement (Kritz, 2012). Based on their MCS scores and the original definitions of the MCS movement categories, the majority of the cross-country skiers in this study would benefit from further evaluation and/or intervention to improve their movement competency prior to adding external load to their strength and gym conditioning programmes.

When reflecting on the high level of gym-based weight training and cross-country skiing skill of our subjects, it would seem their MCS scores, and the individual MCS movement scores, do not reflect the level they are functioning at in their sport. Rather than actual movement impairments, the discrepancy between MCS score and sporting performance may be a function of the subject's unfamiliarity with the specific MCS movement criteria, or an incongruence of the MCS movements or the MCS movement categories, for the sport of cross-country skiing. A study of firefighters performing the FMS reported improvements in FMS score within one testing session simply by providing the subjects with knowledge of the scoring criteria for each movement; however, no carryover was seen to the alignment of the lower extremities during a functional hose pull task (Frost, Beach, Callaghan, & McGill, 2015). While skilled athletes may have sufficient body awareness to evaluate and modify their movement patterns when provided with accurate knowledge of performance requirements in a movement screen, it appears accurate performance requirements of their sporting activities may also be necessary to change sports performance rather than relying on carryover from fundamental movement patterns. As the MCS continues to be used by sports medicine practitioners across various sports and athlete skill level, the score limits for each MCS movement category may warrant further study to ensure the definitions (poor, moderate, and good) and score limits do in fact represent the movement quality intended by the developer. Comparing the MCS scores of athletes determined to have fair, moderate, and good quality movement in their chosen sport may offer some justification for maintaining or modifying the existing MCS movement category limits in the future.

5.1.3.2 Gender differences in MCS scores.

The gender difference in the overall MCS score appears to be due to men scoring higher than women for two individual MCS tasks (push-up, and the twist portion of the lunge and twist task). The scores for the individual movement tasks on the MCS are yet to be found reliable (Dewhirst et al., 2015; Milbank et al., 2016; Reid et al., 2015), and therefore were not included in the statistical analyses. However, consistent with gender differences previously reported for the FMS (Chorba et al., 2010; Schneiders et al., 2011) and MCS (Lee, 2015; Milbank et al., 2016; Reid et al., 2015), the mean score of each individual movement for the men and women in our study was calculated, and observed to differ for only the twist and push-up (Table 4.4 in results chapter).

The push-up task had the most noticeable gender differences, in that the majority of women scored 1/3 while the majority of men scored 3/3. These findings are consistent with other reports of female subjects having inadequate upper-body strength to perform push-ups that meet the MCS 3/3 criteria in adolescent netball players (Reid et al., 2015) and in United States Naval Academy fourth-class Midshipmen recruits (Milbank et al., 2016). This gender difference has also been reported for the FMS where female NCAA soccer, volleyball, and basketball players also exhibited a floor effect in the FMS trunk stability (push-up) task, with only 5% of female athletes scoring a 3/3 for the push-up (Chorba et al., 2010). While our subjects tested strong on their trunk endurance muscle tests, the push-up requires isometric stabilisation of the trunk to avoid hyperextension of the spine during the upper quarter push-up (Cook et al., 2006b; Cook et al., 2014b), and this trunk stabilisation function in the face of strong upper quarter concentric activity is not specifically tested with the McGill or Biering-Sorenson trunk muscle endurance tests used in this study. It appears that for the women in our study, the endurance ability of the trunk muscles did not translate from a static hold to a dynamic upper-body closed-chain push-up that creates a trunk extension force. The push-up task may not be the ideal upper-body task for female athletes who participate in sports that do not require body-weight-resisted closed-chain upper-body movements. The FMS does address the known gender differences for push-up by providing gender-specific performance criteria for the trunk stability push-up task (Cook et al., 2006b); a similar modification to the MCS push-up performance criteria may be warranted given the large gender differences reported thus far for the MCS push-up task (Milbank et al., 2016; Reid et al., 2015).

The twist task also exhibited gender difference with the women's scores biased towards 1/3, while the men's scores were more evenly distributed between 1/3 and 2/3. This gender difference has also been reported previously in the FMS rotary stability task (Schneiders et al., 2011) but not in the MCS lunge and twist task. The twist task challenges the lower trunk to remain stable while the upper trunk is rotating. Our female subjects may have had difficulty stabilising the lower portion of the trunk while moving the upper portion of the trunk due to the poor trunk stability detected in the push-up task.

5.1.3.3 Variation in MCS score by current injury status.

Contrary to expectations, the mean MCS score for cross-country skiers who were currently injured (9 men, 10 women) was not different from the mean MCS score for skiers who were not injured (26 men, 26 women) at the time of testing. The type of injuries our skiers were carrying (shin splints and other lower leg pain, neck and shoulder pain, foot pain, iliotibial band pain, knee pain) did not appear to significantly affect their MCS performance.

5.1.3.4 Is the MCS an appropriate movement screen for cross-country skiers?

After observing the year-round training, roller ski racing, and on-snow racing of elite cross-country skiers, the individual movements of the MCS do reflect components of the movement patterns necessary for efficient cross-country skiing. However, there are some modifications that may warrant consideration. The instructions for the double leg squat may warrant modification to instruct the subject to squat until the thighs are parallel with the ground. This would eliminate the lumbar flexion that occurred when subjects were able to squat lower, but then biomechanically were unable to maintain a neutral lumbar spine, and thus were penalised in their movement score due to their spinal alignment. Cross-country skiers do not require squat strength or endurance in a position of the thigh below parallel with the ground. This modification may be appropriate for all subjects, not just cross-country skiers. The lunge and twist reflects the demands of lower-extremity lunge stability with simultaneous upper-extremity rotation featured in classic cross-country skiing, and to a lesser extent in skate skiing. The push-up task may be better replaced with a pull-up task as cross-country skiers pull their bodies forward over the upper extremities fixed in the snow via the ski pole. The single leg squat reflects well the single limb support phase of both classic and skate cross-country skiing. The bend and pull task offers a valuable opportunity to observe the relative flexibility of the hips and trunk during forward bending. Cross-country skiing does require forward bend at varying degrees depending on slope of the terrain. Of interest to the rehabilitation professional is the ability of an individual to flex at the hips while maintaining a neutral spinal alignment, and then to maintain this body alignment while performing upper-body resistance work. In the case of cross-country skiing, the bend and pull allows evaluation of the skier's functional relationship between hamstring muscle length and trunk stiffness, and their ability to maintain a neutral spinal alignment while strongly recruiting the extensor muscles of the upper extremities. The pull portion of this movement may yield more cross-country ski specificity if an external load were added to the pull. The single leg squat may better reflect the demands of cross-country skiing if the instructions were modified to require a forward step into the single leg squat, and an acceptable squat depth of 70° to 90° knee flexion. This modification has been used in a recent study of dancers (Lee, 2015). In summary, all MCS movements except the push-up correlate with some portion of cross-country ski movement patterns, for more specificity to cross-country skiing, it may be worth eliminating the push-up task, or replacing the push-up with a body weight resisted pull-up, and some minor modifications may be worth considering for the remaining four tasks. These minor modifications may be appropriate for the general population as well as the cross-country ski population.

5.1.4 Muscular measures at enrolment.

Hamstring length and trunk endurance muscle ratios were near the published norms and did not correlate with new injury in this study. Knowing that heavily trained muscles, such as the major hip muscles of skiers, can become shortened with use (Alricsson & Werner, 2004), and that the active straight leg raise test of hamstring length is a component of the FMS, and that the ASLR was used in previous studies of rowers (Newlands, 2013) and dancers (Lee, 2015), the ASLR was included in this study. Given that hamstring length did not deviate from the established norm (Kendall et al., 2005), and did not correlate with new injury, this may not have been a necessary test. The results do show that cross-country skiers generally have adequate hamstring length when compared to the general population norm, and these data are worth knowing as the database of cross-country skier characteristics grows.

The mean trunk muscle endurance ratios for our subjects (0.97 for men, 0.85 for women, 0.91 all subjects) are comparable to the norms reported by McGill et al. (1999) (0.99 for men, 0.79 for women, 0.86 all subjects). However, our data trends towards ratios closer to 1.0, suggesting the trunk flexors of our cross-country skiers may have had greater endurance than the population used by McGill et al. (1999). This is not unexpected considering cross-country skiing requires significant trunk flexor strength and endurance, and is consequently a highly trained muscle group in cross-country skiers compared to the college students used in the study by McGill et al. (1999) from which core ratio norms are generated. It is possible the low number of back injuries reported by our subjects are in part due to their well-trained and relatively stiff trunk muscles (as exhibited by trunk endurance ratios approaching 1.0) providing some protection from back injury. This suggestion is supported by a similar observation from Biering-Sorensen (1984) who noted that men in the general population who exhibited high endurance of the back muscles were protected against low back pain in the follow-up year.

5.1.4.1 Gender differences in muscular measures.

Men who became injured had lower MCS scores and longer left hamstring muscles than those who did not become injured during the study. Biering-Sorensen (1984) reported that men in the general population who have the greatest lumbar spine mobility and the shortest trunk muscle endurance times were more likely to experience first-time low back pain in the following year. It may be interesting to perform further analysis of our data to identify any subjects who reported a new episode of low back pain or hip or posterior thigh injury, and to determine if these subjects exhibited excessive trunk flexion during the MCS bend and pull task, and/or short hamstring muscles (either observed during the MCS bend and pull task, or measured in the active straight leg raise). Women who became injured had shorter right and left hamstring muscles and lower trunk muscle endurance ratios than those who did not become injured, similar to the findings of shorter hamstrings and poorer trunk muscle endurance related to low back pain in females, but not males within the general population (Biering-Sorensen, 1984). Hamstring length may have a different influence on injury risk for men than for women. Trunk muscle endurance may influence injury risk more for female than male cross-country skiers. Lower MCS score may be an injury risk factor for male more than for female cross-country skiers. A larger sample of cross-country skiers and more injury reports are necessary to determine whether these findings are anything more than trends within this cohort of skiers.

5.1.5 Survey response rate.

This study was completed by 57.7% of the subjects. This study used a monthly self-report retrospective survey, requiring a longitudinal commitment from subjects, and thus we were very pleased that our completion rate was comparable to similar self-report retrospective survey studies that only required a one-time commitment (47.1%, Blut et al., 2010; and 53.4%, Ristolainen et al., 2014). Perhaps monthly visits to a ski team practice to remind subjects to complete their surveys would have improved the response rate. There is a delicate balance between encouragement to continue with a study and coercion, as well as inconvenience to coaches and teams to accommodate a monthly visit from a researcher. For these reasons, the study protocol did not include monthly visits by a research team member. No longitudinal self-report survey studies of cross-country skier injuries and training were found for comparison. In contrast, some researchers have reported response rates better than 80% for one-time retrospective surveys (Bahr et al., 2004; Clarsen et al., 2014; Østerås et al., 2013). The one-time commitments required by Bahr et al. (2004) and Østerås et al. (2013) may have influenced the response rates for these studies, although one-time commitments did not yield high response rates for Blut et al. (2010) and Ristolainen et al. (2014). Clarsen et al. (2014) may have positively influenced their response rate by including weekly e-mail weekly reporting to medical staff, and telephone follow-up to nonresponders.

5.1.6 New injuries reported.

There were few new injuries overall (n = 90) during our study. While this is positive for the participating subjects, the low number of injuries did impact our statistical analyses. The low number of new injuries reported are consistent with two recently published studies that reported cross-country skiers as the least injured compared to other endurance sports (long-distance running, swimming, cycling) and team sports (soccer, floorball, handball, volleyball) athletes (Clarsen et al., 2014; Ristolainen et al., 2010). Thus, we were not surprised by the low number of injuries reported in this study.

5.1.6.1 New injuries by chronicity.

In our study, overuse injuries were reported more frequently than acute traumatic injuries, which is consistent with previously reported data for endurance athletes (Ristolainen et al., 2010). The repetitive nature of cross-country ski training and racing, and the individual nature of the sport, reduces, but does not eliminate, the opportunity for traumatic injury events. Acutely injurious events reported during our study occurred more often during nonskiing activities (foot and ankle injuries while running), or in extenuating circumstances while racing (ski pole injuries, falls in photo finishes). This finding is consistent with previous work by Ristolainen et al. (2010) who also reported cross-country skiers sustaining their injuries in sports other than skiing. From these findings, it is evident that attention must be paid to safety, movement technique, and training programmes across all activities in the repertoire of a high-performance athlete, not just in their competitive sport.

5.1.6.2 *New injuries by anatomic region.*

5.1.6.2.1 Lower-extremity injuries.

Lower-extremity injuries were reported most frequently in our study, consistent with previously reported data for endurance athletes (Clarsen et al., 2014; Orava et al., 1985; Ristolainen et al., 2010), and also consistent with a cross-country skier's dependence on power and endurance of the lower extremities. The women in our study reported more lower-extremity injuries, especially ankle and foot injuries, than the men, consistent with the endurance sport athletes studied by Ristolainen et al. (2009). There may be a gender difference in body parts at risk of injury in cross-country skiers. However, the small number of injuries reported, and the small number of subjects in each gender and anatomic injury category, are too small for further analysis. Larger sample sizes in future studies will help to determine the repeatability of these findings, and their value in predicting injury. The mechanisms for gender difference in lower-extremity injuries have been studied primarily in the context of acute anterior cruciate ligament (ACL) and ankle injuries in team sports (Arendt & Dick, 1995; Cowling & Steele, 2001; Hewett, Ford, & Myer, 2006; Hewitt, Myer, Ford, Heidt, & Colosimo, 2005; Mountcastle, Posner, Kragh, & Taylor, 2007; Renstrom et al., 2008) and in the general population (Waterman, Owens, Davey, Zacchilli, & Belmont, 2010). Gender differences in: static and dynamic lower-extremity biomechanical alignment (Hewett, Myer, & Ford, 2006; Hewitt et al., 2005; Renstrom et al., 2008), joint laxity (Hewett, Myer, et al., 2006), strength and flexibility (Hewett, Myer, et al., 2006; Knapik, Bauman, Jones, Harris, & Vaughan, 1991), and hormonal influences (Hewett, Myer, et al., 2006; Renstrom et al., 2008) have been correlated with higher occurrence of noncontact ACL injuries, and ankle ligament injuries, in females. These gender-related influences on ACL and ankle injuries may be factors in the occurrence of the lower-extremity injuries seen in this study. While ACL and ankle injuries are rare in the sport of cross-country skiing, they are common in sports involving running, landing, and cutting movements (Arendt & Dick, 1995; Beynnon, Vacek, Murphy, Alosa, & Paller, 2005; Hewitt et al., 2005; Knapik et al., 1991; Mountcastle et al., 2007; Waterman et al., 2010). Sports involving running, landing, and cutting are often used as part of the general conditioning programme of cross-country skiers. As reported in our subjects, and also in the cross-country skiers studied by Ristolainen et al. (2010), cross-country skiers sustained more of their acute and overuse injuries to the foot and ankle, and these injuries occurred while participating in sports other than skiing, lending reason for investigating lower-extremity alignment, joint mobility, muscle strength, muscle flexibility, and proprioception factors in ongoing injury prevention interventions and studies of cross-country skiers. These findings add further support to the importance of safety, and high-quality movement technique, across all activities in the repertoire of a high-performance athlete.

5.1.6.2.2 Low back injuries.

Low back pain prevalence in our study (4% of all new injuries) was too low for useful statistical analysis. Low back pain prevalence is widely variable in injury studies of cross-country skiers. Comparison with previously published data is made here, but the significance of these comparisons should be considered carefully. Our low prevalence is comparable to the prevalence rates of 11% or lower reported by some authors (Clarsen et al., 2014; Østerås et al., 2013; Ueland Ø & B, 1998), and yet our low prevalence is in contrast to other authors who reported low back pain prevalence rates above 47% in cross-country skiers (Alricsson & Werner, 2006; Bahr et al., 2004;

Bergstrom et al., 2004; Foss et al., 2012). Low back injuries in cross-country skiers require further study before a consensus can be drawn regarding low back pain prevalence. Without consistent low back pain prevalence data, injury prevention strategies cannot be investigated or implemented with any rigour.

It may be that varied training activities outside of cross-country skiing offers some protection against developing low back pain, perhaps due to a change in body position and muscle activity from the repetitive nature of skiing. Swedish adolescent cross-country skiers who participated in another sport on a weekly basis for three or more years did not develop as much low back pain as those exclusively trained in cross-country skiing (Alricsson & Werner, 2006). The variety of training activities reported in our study (cycling, running, roller skiing, skiing—Figure 4.4 in results chapter) may be offering similar protection against injury for our subjects, and thus influencing the low number of injuries reported in our study. In the classic skiing technique, the spine is repetitively loaded from extension to flexion movements with additional rotational loading, while in the skating technique the spine is held in a more vertical position with less rotational loading (Bahr et al., 2004; Ristolainen, 2012). In a large population study, twice as many skiers reported low back pain when classic skiing compared to skate skiing (Bahr et al., 2004). Addressing lower-extremity injury prevention strategies, and the influence of carefully included cross-training (activity variation, as well as ski technique variation), may be key areas to focus on in future injury prevention studies of cross-country skiers.

5.1.6.3 Mechanisms of new injury.

The most commonly reported injury mechanisms were a trip or fall while: running, roller skiing, or, to a lesser extent, skiing. The injury mechanisms are consistent with: the high speeds obtained while roller skiing on asphalt paths; the high number of hours spent running, usually on the undulating terrain of cross-country ski trails or dirt roads; and the unseasonably short snow season during the data collection phase of this study. The short snow season during the time of this study required greater amounts of cross-training due to a lack of skiable snow, and also necessitated ski training and racing on nonideal snow surfaces, increasing the risk for falling or tripping on exposed rocks, tree roots, or ice during the early and late ski season.

Although not statistically significant, more injuries occurred during the off-season when our subjects were running and roller skiing, not snow skiing. The observation of injuries occurring in exercise other than the athlete's specific competitive sport has been reported before (Ristolainen et al., 2010), and may be an important factor to consider in future injury prevention strategies. Movement quality and sport-specific skill in cross-training activities may be as important as it is in the athlete's competitive sport when evaluating injury cause and injury prevention.

5.1.7 Training time/exposure hours reported.

Participants in the current study recorded mean training/exposure hours of 52–56 hours per subject per month, for approximately 600 hours per subject per year. This is consistent with the 550–650 hours per year exposure times reported for European ski high school skiers (Alricsson & Werner, 2005). When comparing our subjects training/exposure hours to those previously reported to influence new injury, our subjects fell below the 700 hours per year reported to be a risk factor for any new injury (Ristolainen et al., 2014), but were equal to the 550 hours per year reported to be a risk factor for low back injury (Foss et al., 2012).

Although our subjects met the 550 hours per year training/exposure time previously reported to increase the risk for low back injury (Foss et al., 2012), we did not see a large number of back injuries in our study. Other positive injury protection factors (e.g., variety of activity, variety of ski technique, and stiffer trunk muscles) may have more strongly influenced our subjects than the negative influence of training/exposure hours. While we did not measure the number of rest days, or any graduated training load increases, these factors would warrant inclusion in future studies as they have been shown to protect against injury (Ristolainen et al., 2014).

Injury risk is also reported to be higher in athletes with less than 2 rest days per week during the training season, and greater than 12 years of active training (Ristolainen et al., 2014). We did not examine our data for the number of rest days per week, but a deeper analysis may allow us to identify the subjects who had sufficient rest built into their programmes and then examine any relationship between rest days and injury. The mean number of years skiing competitively for our subjects (11 years) fell below the previously reported risk factor of 12 years' active training (Ristolainen et al., 2014), which lends some explanation to why this variable did not significantly correlate with new injury in our study.

5.1.8 New injury incidence.

A key objective of this study was to determine the incidence rate of new injuries among a group of elite and collegiate cross-country skiers from northeastern America.

5.1.8.1 Overall injury incidence.

The injury incidence rate for all injuries in our study was 3.81 injuries per 1,000 exposure hours. This is a comparable but slightly higher rate than previously reported rates of 2.10–2.79 injuries per 1,000 exposure hours for cross-country skiers, swimmers, and long-distance runners, but lower than the 5.12 injuries per 1,000 exposure hours reported for soccer players (Ristolainen et al., 2010). No other studies reported injury incidence per 1,000 exposure hours for cross-country skiers. The discrepancy in incidence rate between our study and the only other published cross-country ski incidence rate study (Ristolainen et al., 2010) may be explained by the large difference in sample sizes (41, versus 149 subjects), and perhaps by the increased sampling frequency of our study (monthly for 12 months, versus one retrospective survey for the 12 previous months) leading to more accurate reporting of injury frequency and training hours. It would be valuable to study a larger population of cross-country skiers with the monthly survey frequency over at least two competitive seasons and the intervening off-seasons, to examine any effect the survey frequency, larger sample size, and increased data from each subject have on injury incidence rates. Requiring an in-person enrolment to collect physical measures was a recruitment barrier for this study; a larger population of North American cross-country skiers could be invited to participate in future studies if this barrier could be overcome.

5.1.8.2 Injury incidence by anatomic region.

In our study, the incidence rate for lower-extremity injuries was higher than any other body part, consistent with the previously reported injury incidence patterns (Ristolainen et al., 2014), as well as with previously reported injury prevalence data (Clarsen et al., 2014; Orava et al., 1985). Within the lower-extremity category, 40% of the injuries reported by our subjects involved the foot and ankle (23/58), more than any other body part (Figure 4.3 in results chapter). The high prevalence of foot and ankle injuries is consistent with the reported mechanisms of injury (fall or trip) and the activities the subjects participate in (running, skiing, roller skiing), and it’s also consistent with previously reported studies where foot and ankle injuries in cross-country skiers were the most prevalent or had the highest incidence (Orava et al., 1985; Ristolainen et al., 2010). Clearly, foot and ankle protection, injury prevention, and injury rehabilitation are important for athletes and coaches to focus on at all times. With the relatively high prevalence and incidence rates, even moderate changes to foot and ankle injuries would have positive effects on injury prevalence and incidence.

5.1.8.3 Injury incidence by time of year.

During our study, the injury incidence rate for off-season (5.25 injuries per 1,000 exposure hours) was higher than for ski season (2.27 injuries per 1,000 exposure hours), although not significantly (p = .07). No injury incidence by time of year studies were found for comparison. When comparing injury prevalence during the off-season (75%) and ski season (25%), our injury frequencies are similar to previously reported prevalence rates of 78% preseason and 21% ski season (Østerås et al., 2013). Intuitively, this pattern of higher injury prevalence in the off-season is logical. Off-season training involves high-speed roller skiing on unforgiving asphalt surfaces, increased running on undulating terrain where tripping and falling is higher due to the uneven footing, and often higher overall training volumes (although this was not shown in our study), all of which are potential injury risks. While the ski season is not without injury hazards, such as tripping and falling on exposed rocks, tree roots, or ice, the lower overall speed of movement and the somewhat more forgiving snow surface are factors that likely reduce ski season injury incidence and severity.

5.1.8.4 Incidence of nontraumatic (chronic, overuse) injuries, and acute traumatic injuries.

The incidence of nontraumatic/overuse injuries (2.76 injuries per 1,000 exposure hours) was significantly higher than traumatic injuries (1.05 injuries per 1,000 exposure hours) in this study, consistent with previously reported data (Ristolainen et al., 2010). The noncontact nature, relatively low speeds, and repetitive nature of cross-country skiing create situations conducive to overuse injuries more than acute traumatic events familiar to high-speed downhill skiing, or collision-type team sports such as ice hockey and American football.

5.1.9 Training and racing lost to injury.

Due to injury, a greater percentage of training sessions were modified rather than lost, while a greater percentage of races were lost rather than modified. Our subjects appear to have chosen to modify their training but avoid racing while injured. Raysmith and Drew (2016) reported that the likelihood of achieving a season-long performance goal increased by seven times in elite track and field athletes who completed greater than 80% of planned training weeks during a season. Our subjects reported greater than 90% of races and training sessions were completed. We did not ask our subjects for their season's performance goals, thus we cannot compare our subjects with those studied by Raysmith and Drew (2016). However, it can be seen that our subjects were well within the participation rate necessary for performance success as reported by Raysmith and Drew (2016). In future studies, inclusion of season performance goals and performance outcomes would be beneficial.

5.1.10 Factors correlated with new injury.

5.1.10.1 New injury and MCS scores.

A key finding of this study was that the MCS score did not correlate with reports of new injury of any type in this group of cross-country skiers. This finding rejects our primary hypothesis that new injury is associated with poor movement competency (low MCS score) in cross-country skiers. Although one might expect athletes with poor movement competency to be at an elevated risk for injury, this association has not yet been consistently reported. MCS scores have been positively correlated with new injury in dancers (Lee, 2015), but not correlated with new injury in rowers (Newlands, 2013), or United States Naval Academy fourth-class Midshipmen (Milbank et al., 2016). The results of our study bring to three the number of active populations in which MCS score has not positively correlated with new injury, compared to one study (Lee, 2015) where a positive correlation was seen between MCS score and new injury, thus hinting that MCS score may not correlate with new injury. However, each study is not without limitations, and therefore conclusions about the possible contribution of the MCS to injury prediction in other active populations should be made with extreme care.

New injury and lower MCS scores were positively correlated in a study of dancers (Lee, 2015), but not correlated in populations of rowers (Newlands, 2013) or military recruits (Milbank et al., 2016). When comparing the study populations and sports that have been used to examine the relationship between new injury and MCS score, it can be seen that the intensity and type of activities are quite varied: dance is a dynamic multiplanar jumping, landing, and twisting activity; rowing is a repetitive flexion to extension activity performed in the seated position, while balancing in a narrow vessel moving across water; cross-country skiing is a repetitive flexion, extension, and rotation activity performed while balancing upright on a narrow ski that is sliding across snow; and military recruits are required to perform varied dynamic physical activities, often exercising under the external load of a backpack and/or weapon. It is difficult to consider any of these sports similar to each other, or to the type of activity performed by the general population, and therefore, the relationship between injuries and MCS scores outside of dance, rowing, cross-country skiing, or military training exercises should be interpreted with care until studies with larger sample sizes from these and other active populations have shown agreement one way or the other about the relationship between new injury and MCS score. When agreement is reached with regard to the relationship between new injury and MCS score, the variety of sporting populations that have been studied may then lend support to extrapolating the relationship to other active populations. In addition, there would be value in studying the relationship between new injury and MCS scores in team sports to broaden the MCS database, and provide data for extrapolation to team sports in addition to the endurance sports studied thus far.

The FMS, a similar whole body movement screen to the MCS, has been the subject of a greater number of studies, all of which have focused on team sports or military or general populations. No studies were found describing correlation of the FMS with injury in endurance sport athletes. Like the MCS, the FMS also has inconsistent reports of the relationship between FMS score and new injury. FMS score has been shown to be predictive of officer candidates who will seek medical care for physical harm to their body as a result of participation in officer training (O'Connor et al., 2011), and female NCAA athletes who will seek medical care for a musculoskeletal injury that occurred during participation in team practice or a game (Chorba et al., 2010), but conversely, it has been shown not to predict athletes who will seek medical care for musculoskeletal injuries during an NCAA football season (Hall, 2014; Wiese et al., 2014). Thus, the MCS scores for our cross-country skiers do not yet have a comparable published data set from any whole body movement screen. The data from this study begins the collection of whole body movement screen information in cross-country skiers.

5.1.10.2 New injury and muscular measures.

New injury did not positively correlate with the trunk endurance ratio and hamstring muscle length measures. The 13 males who became injured during the study had a significantly lower MCS score and significantly longer left hamstring muscles than the five males who remained injury free (Table 4.6 in results chapter). The 14 females who became injured during the study had a significantly lower trunk muscle endurance ratio and significantly shorter right and left hamstring muscles than the nine females who remained injury free (Table 4.6 in results chapter). These results may suggest that new injury may be related to different muscular factors for men (lower MCS score, and longer left hamstring muscles) than women (shorter hamstring muscles, and lower trunk muscle endurance ratio). Hamstring length may influence injury differently for male and female cross-country skiers. Trunk muscle endurance may influence injury in female cross-country skiers. However, the small numbers in each of these groups make extrapolation of these results unwise until the outcomes can be reproduced in a larger population of cross-country skiers.

5.1.10.3 New injury and previous injury.

New injury positively correlated with previous injury in our study, which is consistent with the current endurance sport literature (Foss et al., 2012; Fulton et al., 2014; Newlands, Reid, & Parmar, 2015). Bearing in mind this result, injury prevention strategies in endurance sports should focus on the initial injury occurrence, as this is the most consistent and commonly reported predictor of future injuries.

5.1.10.4 New injury and training time/exposure hours.

Contrary to previous reports (Bahr et al., 2004; Newlands et al., 2015; O'Connor et al., 2011; Van Mechelen et al., 1996), new injury in our study was not positively correlated with training/exposure time; however, a trend was seen for new injury to increase as monthly running time increased. Since our cross-country skiers most frequently injured their lower extremities during a trip or fall while exercising, this trend of increased running and increased injury is logical, and the small study population with low total injuries likely affected the significance of this statistic.

5.1.11 New injury risk factors.

Consistent with the current literature (Bahr et al., 2004; Foss et al., 2012; O'Connor et al., 2011; Van Mechelen et al., 1996), past injury report was a significant predictor of new injury when accounting for overall training time, run time, and MCS score in the risk factor analysis. Due to insignificant statistical relationships between new injury and our other independent variables, little else can be concluded from the risk factor analysis.

We found no significant relationship between new injury and hamstring length. Although the women who became injured did have significantly shorter hamstring muscles than women who remained injury free, the 6° difference in mean hamstring length between injured and noninjured female skiers is not likely to be clinically relevant as it is small enough to be the result of measurement error in this sample size (Norkin & White, 2003). Norkin and White (2003) report the mean standard deviation of repeated range of motion measures of extremity joints taken by different examiners is 5° to 6°. Therefore, to show a difference between two measures taken by different testers, the values must differ by 6° to 12° (1–2 standard deviations). The small difference could also be due to statistical calculation artefacts in this small sample, as it is not seen when all subjects are combined. Gender differences in the effects muscle length has on injury risk may be a future direction for injury research.

There was no significant relationship between new injury and trunk muscle endurance ratio in our skiers. The skiers with trunk muscle endurance ratios closest to 1.0 (indicating potentially stiffer torsos) might be expected to have fewer trunk injuries, as better sport performance has been linked with having a stiffer torso in NCAA basketball players (McGill et al., 2012). The mean core ratio in our study was 0.91, and there were very few back injuries reported in our study, suggesting that perhaps the trunk muscle endurance ratio was protective for this population, but there were insufficient low back injuries for any useful statistical analysis to support this idea.

5.2 Limitations

As with all research projects, compromises were required to complete the study in a timely manner, and some of these compromises led to limitations in this study. For the purposes of this initial study it was decided to keep the data collection to one season. Thus, while statistical power could have been enhanced, and further statistical analyses could have been conducted with a greater number of subjects, and surveys spanning multiple ski seasons, this could not be achieved within the scope of this project.

The completion rate for our study (57.7%) was lower than the 80% we had used in our power analysis, thus affecting significance levels in the statistical analyses. In retrospect, 50% would have been a better estimated response rate to use in our power analysis, which would then have required an even greater number of subjects be recruited to ensure statistical power. Regardless of the subject numbers required from a more realistic power analysis, the absolute number of subjects that could realistically be recruited continues to be limited by the number of NCAA and professional cross-country skiers willing to participate in a year-long research study who also live within a day's drive of the primary investigator's residence. All potentially eligible skiers within a day's drive of the primary investigator's residence were approached via their team coaches during the recruitment phase of the study, and without using coercion, two professional teams and four NCAA teams agreed to participate.

Retrospective survey studies have two main categories of recall bias: a memory decay, which means the loss of information due to failure to recall the event, and the telescoping effect, which is the tendency to remember events in the past as if they occurred closer to the present than they actually did (Ristolainen et al., 2010). Our monthly survey frequency aimed to reduce the effects of both categories of recall bias; however, recall bias over a 30-day period could still be considered a limitation of this study.

5.3 Conclusions

This is the first study to report MCS scores in cross-country skiers and to examine the relationship between MCS score and new injury recorded monthly for 12 consecutive months. Contrary to our primary hypothesis, MCS score did not correlate with new injury in this population of cross-country skiers.

Previous injury positively correlated with new injury, which supports one of the secondary hypotheses that new injury is associated with a history of injury. As injury history was the strongest predictor of sustaining another injury, coaching and medical staff should consider each skier's lifetime injury history when determining which athletes are indicated for detailed medical team assessments prior to beginning a training programme.

A long career in cross-country skiing, high training hours, a higher number of training hours spent running, a higher number of training hours spent roller skiing, poor trunk muscle endurance, and shortness of the hamstring muscles were not associated with new injury in this population of cross-country skiers.

The low injury incidence of 3.81 new injuries per subject, per 1,000 hours of training, was comparable with populations of other endurance sport athletes. There was a higher incidence of injuries during the off-season, but it was not significantly different from the incidence of injuries during the ski season ($p = .07$). Consistent with the noncontact, highly repetitive, endurance nature of cross-country skiing, there was a significantly higher incidence of nontraumatic/overuse injuries than acute traumatic injuries (p = .02), and a significantly higher incidence of lower-extremity injuries than any other body region (upper extremity, trunk, low back; $p < .05$).

The MCS scores, muscle length and strength measures, injury data, mechanisms of injury, and injury incidence data collected during this study contribute to the body of knowledge about cross-country skier movement patterns and injury incidence, as well as providing baseline data for further movement and injury studies, and future research and clinical injury prevention strategies.

5.4 Clinical Implications

Coaching, medical, and research teams associated with cross-country skiing and other endurance sports will find the injury and movement competence data collected in this study valuable in understanding injury incidence and risks for injury in cross-country skiers. To instigate clinical and research based injury prevention measures, robust baseline injury incidence and screening data such as ours is required.

As new injury increased so did the number of training hours spent running (p = .08), which corresponds with previous reports of elevated injury frequency during periods of high training volume. Given that excessive training load and insufficient recovery time are consistently reported injury risk factors, coaches may see reduced injury rates simply by ensuring two rest days during the off-season, and fewer than 700 hours training per year as suggested by Ristolainen et al. (2014). Recently, Gabbett (2016) has proposed that athletes may benefit from determining their ideal training stimulus, the intensity and load that maximises the individual's net performance potential while limiting the negative consequences of excessive or insufficient training (e.g., injury, illness, fatigue, and overtraining). Rather than prescribing a number of training/exposure hours, Gabbett (2016) proposes monitoring the acute:chronic workload ratio for optimal long-term reduction in training-related injuries. In this case, acute workload is the day-to-day effect of a workout, and chronic workload is the amount of work an athlete is currently physically conditioned to tolerate. This may be a useful concept to guide the development of training programmes for cross-country skiers. A week that includes a ski race, or maximal-effort workouts, may require a reduction in overall exposure time to prevent injury or illness due to overtraining later in the season.

Participation in a variety of cross-training activities (soccer, aerobics, running, downhill skiing, floorball, volleyball, and cycling) has been reported to protect against injury (Alricsson & Werner, 2006), and thus, including a variety of physical activities in any athlete's training programme may also reduce injury rates, provided the athlete is proficient at the movement patterns required by the cross-training activities.

The MCS is a tool that can be used to identify athletes with movement patterns that deviate from the standard defined in the MCS scoring criteria. The MCS may also be a useful tool to educate skiers on movement control and alignment during strength and conditioning training as part of an injury prevention strategy.

5.5 Future Directions

Future work can expand the cross-country skier movement and injury knowledge base by addressing the following topics.

Preventing the first injury appears to be the most significant factor in reducing the occurrence of new injuries to cross-country skiers. Fair argument can also be made for injury prevention strategies to be aimed at the junior development, pre-elite athlete by addressing movement technique and training habits while the athlete's body is undergoing neuromusculoskeletal development and before significant injury has been sustained. Screening may be useful in these development team athletes to assess their movement competence to ensure it is appropriate for their sport-specific activities and training load prior to the athlete developing any acute or overuse injury symptoms. The results of screening can be used to educate the athlete about their movement competence and quantify changes in movement pattern in response to interventions. Now that baseline MCS scores for elite cross-country skiers have been reported, these could also be used to educate junior development athletes about skier movement patterns, and set goals for future MCS testing sessions.

Successful initial injury prevention strategies in the injury-free athlete of any age are important, and are likely to be different than the strategies necessary to prevent subsequent injuries in previously injured athletes. The previously injured active recreational adult and high-performance athlete are more commonly encountered than the never-injured athlete; thus reduction and prevention of subsequent injuries in the skeletally mature athlete is also important work. Understanding the relationship between specific injuries and subsequent injuries may be important in identifying effective injury reduction and prevention strategies. This work has begun: Foss et al. (2012) have reported that the only risk factor for low back pain was having low back pain in the previous 12 months in a cohort of former endurance athletes, and Fulton et al. (2014) have reported that injury risk is altered by previous injury. In a systematic review of injury studies in active healthy populations, ACL injury, hamstring injury, Achilles rupture, and ankle sprain injuries have been linked to subsequent injury of the same limb or the same body part on the contralateral limb (Fulton et al., 2014). Exploring the relationships between specific injuries and subsequent injuries in cross-country skiers would expand on the low back pain work of Foss et al. (2012).

Expanding the study population size by recruiting more skiers, as well as collecting information across multiple seasons and training cycles, will allow comparison between subjects and between seasons, and will provide a more robust foundation for injury prevention strategies to be developed and studied. Cross-country skiers do not appear to become injured as frequently as other endurance athletes, and certainly not as frequently as athletes participating in team sports (Ristolainen et al., 2010). Larger populations of cross-country skiers than other athletes may need to be studied to capture enough injuries to permit statistically powerful analyses of subgroups of injuries and participants. Seasonal unpredictability provides another rationale for conducting future studies over the course of two or more seasons to better account for the unpredictable nature of snowfall. Skiable snow arrived late and melted early during the study year, resulting in early- and late-season ski training and racing being hampered by wet, rocky, and/or icy surfaces.

The current study sample size was limited by the geographical distance between the researcher and the subjects. The geographical barrier could be overcome by accepting a recording of the subject performing the MCS recorded by a team member or local sports medicine professional, thus allowing subjects to participate without requiring an in-person enrolment meeting with the researcher. This would require establishing a simple but precise instruction set for recording and sharing the MCS using a commonly available device such as a smartphone. The sharing of the MCS video between the subject and the researcher would need to conform to the regulations governing safety and sharing of private health information specific to the jurisdiction where the study is conducted and the data are collected. Once established, this method could also be useful to coaches wishing to consult with researchers and sports medicine professionals with greater experience in analysing movement screens. A recent study in North America did use MCS recordings made by a local member of the sports medicine team at the United States Naval Academy. Some difficulties were encountered when evaluating the MCS videos due to inadequate capturing of the entire movement pattern, less than optimal camera angle, and loose-fitting clothing that obscured the raters' view of the lumbar spine necessary for scoring the MCS movements (Milbank et al., 2016).

With careful modifications to the recording instructions, these barriers could be overcome in the future.

Differentiating between training and racing lost to injury versus illness may be useful in future studies to further investigate the recent findings of Raysmith and Drew (2016) who reported that in high-performance track and field athletes, the majority of new injuries occurred within the first month of the six-month preparation season, while most illnesses occurred within two months of an athlete's major competition/event for the season. Further to the differentiation between injury and illness, athlete questionnaires that link time loss to a specific injury or illness will eliminate assumptions about which risk factors resulted in the interruption to training or racing.

Exploring the relationship between activity type/mode of training and injury incidence may reveal injurious activities for cross-country skiers that could be modified, reduced, or removed from training to reduce injury. For example, our subjects reported a number of foot and ankle injuries due to trips and falls while running. Perhaps if these skiers had employed less running and more cycling in their off-season conditioning, the foot and ankle injury rate would have been lower.

This study relied on the subjects to report the occurrence of an injury, whether the injury was sustained traumatically (e.g., during a trip, fall, or collision), as well as the anatomic location of their injuries. Including the medical teams for the subjects in future studies would allow comparison of the medical diagnosis, type, and duration of treatment with the subject-reported information. This would make for valuable study of subject recall versus medical reports. If a subject did not report their injuries to the medical team (perhaps due to the injury being of minimum impact and/or the subject not wishing to disclose the injury), these would be injuries lost to analysis.

Recording whether subjects met their predetermined seasonal performance goals, and exploring the relationship between this performance and their seasonal injury, illness, training, and movement patterns, may be a more engaging method of surveillance for athletes and coaches, while also providing researchers, coaches, and medical staff with practical information for subsequent individual and group injury prevention strategies.

Bahr (2016) recently published a critical review that supports an IOC call for more large-scale studies evaluating the components of athlete history and examination that can be used identify athletes at an elevated injury risk. This study of cross-country skiers, their demographics, their movement patterns, and their monthly reports of injury and training patterns over 12 months has done this for a cohort of cross-country skiers. Ongoing movement screening studies are suggesting that generic movement screening may not be as useful for injury prediction as initially hypothesised. Generic screening may not be the best identifier of movement competency and/or injury risk for the elite athlete. For example, the MCS and FMS have both been shown to exhibit a floor effect for the push-up task for female subjects. In future studies of cross-country skiers, the relationship between: movement competency, ski technique, and/or injury; and hamstring length, trunk muscle endurance, lumbo-pelvic flexion rhythm (examining the relationship between relative or absolute hamstring stiffness, and lumbar spine stiffness), and an upper-extremity pull-up task may yield helpful results in the search for the characteristics of cross-country skiers who are resilient to injury. Future studies must continue by taking the step to identify at-risk athletes, offer interventions intended to reduce injury risk, and show a change in injury rate. Injury risk that is identified from regular health examinations/physical screenings will be far more useful if the results are then paired with intervention programmes that reduce the actual injury rate. Screening for injury risk cannot be useful without interventions to change the findings of the screen when it is repeated on the same individuals. Such a study could use MCS scores, injury history, training load reports, and other movement test outcomes to identify cross-country skiers who would benefit from further physical assessment, specific conditioning, or load modification, and to guide injury prevention programmes focusing on optimising the control of the lower extremities and trunk. MCS scores and/or other movement test outcomes could be used to educate skiers about their movement competency to guide their specific conditioning, load modification, and injury prevention strategies.

6 Bibliography

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7 Appendices

7.1 AUTEC Ethics Approval

AUTEC
SECRETARIAT

4 September 2014

Duncan Reid
Faculty of Health and Environmental Sciences

Dear Duncan
Re Ethics Application: **14/268 Nordic skiers' movement patterns and injury incidence.**
Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).
Your ethics application has been approved for three years until 4 September 2017.
As part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 4 September 2017;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 4 September 2017 or on completion of the project.

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.
AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.
To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.
All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee
Cc: Sonya Worth sworth@uvm.edu

7.2 UVM Ethics Approval

The UNIVERSITY of VERMONT
Committees on Human Subjects
Serving the University of Vermont
and Fletcher Allen Health Care

RESEARCH PROTECTIONS OFFICE
213 Waterman Building
85 South Prospect Street
Burlington, Vermont 05405
(802)656-5040 ph
www.uvm.edu/irb/

Memorandum

TO:	Sonya Worth
FROM:	Gale Weld
DATE:	04-Aug-2014
SUBJECT:	CHRMS: 14-554 Nordic Skiers' Movement Patterns and Injury Incidence

Attached is a signed assurance form which certifies this application has been reviewed and approved. Also attached is the IRB's list of key personnel for this protocol.

Enclosed is a stamped copy of your currently approved informed consent form. Please make sure that you are using the approved forms at all times. All previous versions (hard copy and Word) should be removed to avoid misuse and confusion with future submissions.

As the Principal Investigator of this approved protocol you have specific responsibilities. Please refer to the Research Manual, Section 9. Submission of Materials After Initial Approval is Obtained and Section 10. Investigator Responsibilities to review these responsibilities and obtain further guidance.

cc: Sharon Henry

The UNIVERSITY of VERMONT
Committees on Human Subjects
Serving the University of Vermont
and Fletcher Allen Health Care

RESEARCH PROTECTIONS OFFICE
213 Waterman Building
85 South Prospect Street
Burlington, Vermont 05405
(802)656-5040 ph
www.uvm.edu/irb/

CHRMS: 14-554

Protection of Human Subjects Assurance

Title: Nordic Skiers' Movement Patterns and Injury Incidence
Principal Investigator: Sonya Worth,
Institution: University of Vermont and State Agricultural College, Burlington, VT 05405

This institution has an approved assurance of compliance on file with the Department of Health and Human Services which covers this activity.

University of Vermont and State Agricultural College: FWA 00000723 Expiration Date: Nov 12, 2018
Fletcher Allen Health Care, Inc.: FWA 00000727 Expiration Date: April 18, 2019
IRB number 00000485

Certification of IRB Review

This activity has been reviewed and approved by an IRB in accordance with the requirements of 45 CFR 46, including its relevant Subparts; and, when applicable, with the requirements of 21 CFR 50 and 21 CFR 56.

Date of approval AUG 01 2014 Date of expiration JUL 31 2015

IRB Review Type: Expedited review

Institutional Signature/Date: ____________
Name and Title of Official: David A. Kaminsky, M.D., Associate Chair,
Committee on Human Research in the Medical Sciences

7.3 Middlebury College Ethics Approval

Middlebury

Middlebury College
Middlebury, Vermont 05753

Institutional Review Board 802.443-5029

October 7, 2014

Sonya G. Worth

UVM

Dear Sonya,

Your proposal (14551, Nordic Skiers' Movement Patterns and Injury Incidence) was reviewed by the Middlebury Institutional Review Board (IRB) on October 7, 2014 through the normal process for an exempt proposal. Your proposal is now approved.

Please check http://www.middlebury.edu/academics/resources/irb/deadlines to ensure that you apply for renewal in time to prevent your approval from expiring.

If the project will run for longer than 12 months, you must renew this approval no later than October 7, 2015.

It is important that you inform the committee promptly should you encounter any unanticipated problems involving risks to subjects or others associated with your research. Please inform the committee when the study is completed and forward copies of publications or conference presentations based on this project to Eileen Brunetto, IRB Coordinator, MBH 412, for our institutional records.

Good luck with your research.

Matthew Kimble, PhD

Matthew O. Kimble

IRB Chair

7.4 Bowdoin College Ethics Approval

BOWDOIN COLLEGE

Institutional Review Board

November 17, 2014

Sonya Worth (Nathan Alsobrook)
University of Vermont

The Institutional Review Board (IRB) has received your protocol titled "Nordic Skiers' Movement Patterns and Injury Incidence" and has assigned it number IRB #2014-36.

Please make record of this number and use it for any further correspondence with our committee.

This protocol has been **approved** by the Bowdoin College IRB. During the review of this project, the IRB specifically considered (i) the risks and anticipated benefits, if any, to subjects; (ii) the selection of subjects; (iii) the procedures for securing and documenting informed consent; (iv) the privacy of subjects and confidentiality of the data; and (v) special provisions necessary for vulnerable populations, if any.

You are authorized to implement this study as of November 17, 2014.

Approval for this study is granted for one year, and **will expire on November 16, 2015**. At that time, if you wish for the study to remain open and active, you will be required to submit a *continuing review form.*

Each subject enrolling in this study must sign the IRB-approved consent form that you submitted with this protocol. Any changes to the consent form must be approved by the IRB before use.

This project must be conducted in full accordance with all applicable sections of the IRB guidelines. Any proposed changes to the project should be submitted to the IRB for review using the *modification form*. This must be done before implementation of any changes.

Any unanticipated problems or risks to participants should immediately be reported to the IRB using the *adverse event form.*

If you have any questions, please contact Samuel Putnam, chair of the IRB at irb@bowdoin.edu or x3152.

Samuel Putnam
Chair, Institutional Review Board

8400 College Station · Brunswick · Maine 04011-8484 · *Tel* 207-725-3152 · irb@bowdoin.edu

7.5 Informed Consent

Informed Consent

Title of Research Project: Nordic Skiers' Movement Patterns and Injury Incidence

Principal Investigator: Sonya Worth, PT PGDipHSc OCS

Primary Supervisor: Dr Duncan Reid, DHSc, MHSc (Hons) BSc, Dip Physio, Dip MT, PGD (Manipulative Physiotherapy) FNZCP, Associate Professor of Physiotherapy

UVM Faculty Sponsor: Sharon Henry PT, PhD, ATC, Professor of Rehabilitation and Movement Science

You are being invited to participate in a study on injury incidence and movement coordination in Nordic skiers. This study is being conducted by the Department of Rehabilitation and Movement Science at the University of Vermont and the School of Rehabilitation & Occupation Studies at the Auckland University of Technology, Auckland, New Zealand. This study completes the requirements for a Masters of Health Science at Auckland University of Technology for the Primary Investigator, Sonya Worth, PT, PGDipHSc, OCS. You have been chosen to participate because you are a Nordic skier who is between the ages of 18 and 65 years and participating in competitive Nordic ski racing. You are encouraged to ask questions and take the opportunity to discuss the study with anybody you think can help you make this decision.

The Purpose of the Research: In recent years there has been growing interest within the sport and health professions to assess athletes' movement capability with various movement-screening tools that are designed to identify athletes' movement patterns. The assessment of movement patterns attempts to identify faulty patterning, which could be indicative of impaired mobility, decreased strength, and/or poor motor control, and may predispose the athlete to injury. The importance of pre-participation athletic screens is well established in international sport programs. The Movement Competency Screen (MCS) is gaining popularity in the literature and has been used with Olympic Rowing Teams and competitive Netball teams in New Zealand. Given that Nordic skiing is a very repetitive activity, Nordic athletes may be prone to overuse injuries, and faulty movement patterns may predispose athletes to injury and be even more important to athletes who train with high volumes of repetitive activities. The purpose of this research is to understand the movement patterns of competitive Nordic skiers and to also plot injury incidence against racing and training load over a 12 month training cycle. These data will facilitate further discussions about movement patterns, the importance of screening, and the incidence of injuries during a Nordic skier's year; it will be the basis for future studies to assess injury risk and perhaps influence injury prevention programs.

The Number of Participants: 74 participants

What the Study Involves: Once you agree to the terms of this study (indicated by your signature on this consent), you will be asked to complete a brief demographic form (this will take about 15 minutes to complete). This form will ask about your skiing history, handedness, and current and past injuries. It may be completed anytime during the two days prior to the movement testing, or at the time of the movement testing. Movement testing and initial monthly questionnaire completion will take place at a time, date and location convenient to you and your team (this will most probably be during a ski practice or team meeting). You will perform the 5 tests that comprise the MCS tool and these movements will be video recorded for later scoring (this will take about 10 minutes). Prior to each of the 5 movements you will receive verbal instructions and watch a video demonstration. You will also perform a hamstring muscle length test, and 2 trunk muscle endurance tests, this group of tests will take another 10 minutes. You will be given verbal and written instructions for each of these tests. Every month for 12 months you will be asked to complete a 20 minute electronic questionnaire about your training load, race participation and any injuries over the month. This will be emailed to you at the address you provide on the Athlete Intake Form. By clicking submit/complete at the end of each monthly questionnaire you will be entering your data into the study.

Withdrawal from the Study and/or Being Withdrawn from the study: During testing, if you are demonstrating significant fatigue such that you could not complete the testing, the session will be terminated. If you experience any pain while performing the tests, the session will be terminated. You can refuse further participation at any time for any reason. Refusing further participation will not result in any penalty. If you withdraw after the data collection has started, we may use the data that has already been collected. Refusing further participation will not result in any penalty.

Risks or Discomforts: Although this testing involves common everyday movements, there is a small possibility that discomfort or pain will be felt during the movements. This study is neither designed nor intended to detect health problems; if you suspect that you might be suffering from injury, you should not rely on this study as a way to determine your health status.

Benefits of Participating: There are no direct benefits to you for participating in this study; however, your participation will benefit both the sport of Nordic skiing and health professionals (e.g., physical therapists, athletic trainers, etc.). The findings from the study will give Nordic ski coaches, trainers, and physical therapists a better understanding about how 18 - 65 year old Nordic skiers move during the MCS movements. In the future, this information will hopefully improve injury prevention and treatment programs for Nordic athletes.

Costs or Compensation for Participating: The only cost to participate is your time. The total compensation available to you is $US80. Compensation is offered in increments of $US20 after completion of the third, sixth, ninth and twelfth month surveys. Compensation will be mailed to you at the address you provide. The New Zealand Manipulative Physiotherapists Association has generously provided the funds for this compensation package in the form of a financial grant to Sonya Worth (Primary Investigator). This grant may only be used for subject compensation.

Please provide your mailing address here:
(write neatly!!)
Name:
Address:

Confidentiality: The questionnaire data and videotapes will be kept in a secure, locked area. Computer files will be kept on a password-protected computer. Only the investigators will have access to the data. You will be identified only by a code number on the video recordings. The videos and questionnaire data will be destroyed upon publication of the study. Any publication will not include personal information and scoring data will not be identifiable. Representatives of the Institutional Review Board (IRB) and regulatory authorities will be granted direct access to your research record for verification of study procedures and/or data. Study data will be collected and managed using REDCap electronic data capture tools hosted at University of Vermont. REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies. At the University of Vermont, REDCap is housed in a HIPAA compliant data center within the hospital's firewall. The REDCap database is backed up nightly.

Contact Information: Sonya Worth PT PGDipHSc OCS is the investigator in charge of this study and can be contacted at the address or phone number below for more information about this study. If you have questions about your rights as a participant in a research project, or how to proceed should you believe that you have been injured as a result of your participation in this study, you should contact Nancy Stalnaker, the Director of the Research Protections Office at the University of Vermont at 802-656-5040.

Statement of Consent: You have been given and have read, or have had read to you, a summary of this study. Should you have further questions about the research, contact the person conducting the study at the address and telephone number below. Your participation is voluntary. You may refuse to participate or withdraw at any time without penalty or prejudice. If you agree to participate, please sign the form below.

This form is valid only if the Committees on Human Research's current stamp of approval is shown below.

____ __________

Signature of Subject Date

____

Name of Subject Printed

____ __________

Signature of Principal Investigator or Designee Date

____

Name of Principal Investigator or Designee Printed

Principal Investigator: Sonya Worth, PT PGDipHSc OCS
Address: 305 B Rowell, 106 Carrigan Dr, Burlington, VT 05405
Telephone: 802-656-3252 (leave message)
E-mail: sonya.worth@uvm.edu

Additional Contact Information:

Middlebury College Athletes, if at any time you have comments or concerns regarding the conduct of the research or questions about your rights as a research subject, you should contact:

Matthew Owen Kimble, Ph.D.
Chair, Middlebury Institutional Review Board
Associate Professor
Department of Psychology
Middlebury College
Middlebury VT 05753

Phone: 802 443 5402
Fax: 802 443 2072
Email: mkimble@middlebury.edu

Bowdoin College Athletes, if at any time you have comments or concerns regarding the conduct of the research or questions about your rights as a research subject, you should contact the Bowdoin College Institutional Review Board Chairperson:

Samuel Putnam at (207) 725-3152.
Or, you may write to the IRB in care of:
Professor Samuel Putnam,
Department of Psychology,
6900 College Station,
Bowdoin College,
Brunswick, ME 04011.

If Professor Putnam is not available, you should contact the IRB Administrator:

Jean Harrison at (207) 725-3217.
Or write her at:
Jean Harrison,
Academic Department
Coordinator, 8400 College Station, Bowdoin College, Brunswick, ME 04011.

Both Professor Putnam and Mrs. Harrison can be reached at: IRB@bowdoin.edu.

7.6 Movement Competency Screen Instructions

Movement Competency Screen

MCS

HOW ATHLETES PRODUCE POWER IS MORE IMPORTANT THAN THE POWER THEY PRODUCE

Developed by Matt Kritz

Movement competency is described as the ability to move free of dysfunction or pain. Movement dysfunction has been expressed as movement strategies that contribute more to injury than performance. An athlete's movement competency is influenced by several variables. The responsibility of the strength and conditioning professional is to insure that the training prescribed enhances performance and does not contribute to injury. The best way to improve movement, is to move. However, movement under a load greater than what the athlete's movement competency can support will force the athlete to compensate and over time compensation will negatively affect health and performance. The objective of the movement competency screen (MCS) is to identify which fundamental movement patterns can be aggressively loaded and which require developmental attention.

The fundamental movement patterns that are evident in activities of daily living and strength training programs to varying degrees are; the squat pattern, lunge pattern, upper body push pattern, upper body pull pattern, bend pattern, twist pattern, and single leg squat pattern.

The MCS is made up of five movements that provide the athlete with an opportunity to demonstrate their movement competency within each fundamental pattern. The MCS movements are performed with a body weight load and are the squat, lunge-and-twist, bend-and-pull, push up, and single leg squat.

To use the MCS to screen your athlete's movement competency, video record or watch an athlete perform three repetitions of each of the MCS movements from the front and side. Refer to the MCS criteria to identify which areas do not match the screening criteria. Use the MCS screening sheet to document the primary and secondary areas you believe are problematic based on the screening criteria. Add up the primary and secondary marks to determine the load level for each pattern.

The load levels are variable resistance that challenge the pattern in a progressive manner. The load levels are level 1) assisted, 2) body weight and 3) external mass. The objective of progressing a pattern with an accommodating load is to challenge the pattern with a resistance that facilitates good mechanics. In other words use a load level that allows the athlete to perform the fundamental pattern correctly. Level 1 assists the pattern by attenuating the body weight force. Level 2 challenges the pattern with the body weight force. Level 3 introduces modalities to body weight that provide further external resistance such as free weights.

The MCS is a simple tool that will provide valuable information about an athlete's movement ability and offer the strength and conditioning professional programming solutions to ensure the athlete's movement competency can accommodate the desired training.

Here is what to instruct the athlete to do for each MCS movement.

BODY WEIGHT SQUAT

Perform a body weight squat with your fingertips on the side of your head. Squat as low as you comfortably can.

LUNGE & TWIST

Cross your arms and place your hands on your shoulders with your elbows pointing straight ahead. Perform a forward lunge then rotate toward the forward knee. Just rotate toward the knee then return to center and return to the standing position. Alternate legs with each rep.

PUSH UP

Perform a standard push up

Bend & Pull

Start with your arms stretched overhead. Bend forward allowing your arms to drop under your trunk. Pull your hands into your body as if you were holding onto a bar and performing a barbell rowing exercise. Return to the start position with your arms stretched overhead.

SINGLE LEG SQUAT

Perform a single leg body weight squat with your fingertips on the side of your head and the non-stance leg positioned behind the body. Squat as low as you comfortably can.

7.7 Movement Competency Screen Scoring Criteria

PATTERN	SCREENING CRITERIA
SQUAT	**HEAD** - Centered **SHOULDERS** - Held down away from the ears. Elbows held behind the ears throughout the squat. **LUMBAR** - Neutral throughout the squat **HIPS** - Movement starts here, aligned and extension is obvious **KNEES** - Stable, aligned with the hips and feet **ANKLES / FEET** - Aligned with the knees and hips. In contact with the ground especially the heels at the bottom of the squat and feet appear stable **DEPTH** - Thighs parallel with the ground **BALANCE** - Maintained
LUNGE & TWIST	**HEAD** - Centered **SHOULDERS** - held down and away from ears, rotation occurs in the thoracic region of the spine **LUMBAR** - Neutral position, does not hyper extend during lunge, does not flex laterally during the twist, appears to be stable during rotation **HIPS** - Horizontally aligned, accommodates stance width with obvious mobility **KNEES** - Aligned with the shoulder, hip, and foot. Front and back leg in a 90 degree position **ANKLES** - Directly under the front knee and aligned with the back knee **FOOT** - Heel of lead leg in contact with the floor, trail foot flexed and balanced on forefoot **DEPTH** - Lead thigh parallel with the ground **BALANCE** - Maintained for each leg
PUSH UP	**HEAD** - Centered **SHOULDERS** - Held down and away from the ears, hands positioned directly underneath shoulders, scapulae in a good position at the start, moving in a rhythmic motion throughout the movement **LUMBAR** - Neutral, does not extend or flex during the movement **HIPS** - Aligned with trunk and held stable **KNEES** - Held stable **ANKLES** - Aligned **FEET** - Aligned **DEPTH** - Chest touches the floor **BALANCE** - Maintained
BEND & PULL	**HEAD** - Centered and moves with trunk **SHOULDERS** - Held down and away from the ears when arms are extended overhead. Scapulae remain in a good start position as the hands drop below the torso to begin the pull. Scapulae moving in a balanced and rhythmic motion during pull with obvious protraction and retraction **LUMBAR** - Neutral spine maintained during bend. No flexion during bend or hyper extension during standing with arms overhead **HIPS** - Bend is initiated here with no shifting left or right with pelvis position maintained during the movement **KNEES** - Aligned and not hyper extended **ANKLES** - Aligned **FEET** - Aligned **DEPTH** - Trunk parallel with the ground **BALANCED** - Maintained
SINGLE LEG SQUAT	**HEAD** - Centered **SHOULDERS** - Held down away from the ears. Elbows held behind the ears throughout the squat. **LUMBAR** - Neutral throughout the squat **HIPS** - Movement starts here, aligned and extension is obvious **KNEES** - Stable, aligned with the hip and foot **ANKLES** - Aligned with the knee and hip **FEET** - In contact with the ground especially the heel at the bottom of the squat and appears stable **DEPTH** - Thigh parallel with the ground **BALANCE** - Maintained for each leg

MCS — Movement Competency Screen

HOW ATHLETES PRODUCE POWER IS MORE IMPORTANT THAN THE POWER THEY PRODUCE

Developed by Matt Kritz

Athlete **Sport** **Date** **MCS Score**

SCREENING INSTRUCTIONS: Based on the MCS criteria mark the PRIMARY or SECONDARY area that is of concern when observing the athlete perform the MCS movement patterns.

PATTERN	PRIMARY	SECONDARY	LOAD LEVEL	COMMENTS
SQUAT	○ SHOULDERS ○ LUMBAR ○ HIPS ○ ANKLES/FEET	○ HEAD ○ KNEES ○ DEPTH ○ BALANCE	1 2 3	
LUNGE & TWIST (The Lunge)	○ BALANCE ○ LUMBAR ○ HIPS ○ ANKLES/FEET	○ HEAD ○ KNEES ○ DEPTH	1 2 3	
LUNGE & TWIST (The Twist)	○ SHOULDERS ○ LUMBAR ○ HIPS ○ ANKLES/FEET	○ HEAD ○ KNEES ○ DEPTH ○ BALANCE	1 2 3	
BEND & PULL (The Bend)	○ SHOULDERS ○ LUMBAR ○ HIPS ○ DEPTH	○ HEAD ○ KNEES ○ ANKLES/FEET ○ BALANCE	1 2 3	
BEND & PULL (The Pull)	○ SHOULDERS ○ LUMBAR ○ HIPS ○ DEPTH	○ HEAD ○ KNEES ○ ANKLES/FEET ○ BALANCE	1 2 3	
PUSH UP	○ HEAD ○ SHOULDERS ○ LUMBAR ○ DEPTH	○ HIPS ○ KNEES ○ ANKLES / FEET ○ BALANCE	1 2 3	
SINGLE LEG SQUAT	○ DEPTH ○ LUMBAR ○ HIPS ○ ANKLES / FEET	○ HEAD ○ SHOULDERS ○ KNEES ○ BALANCE	1 2 3	

SCORING INSTRUCTIONS

Load Level	PRIMARY		SECONDARY	Considerations
1	2+	and / or	4	The numbers in the PRIMARY and SECONDARY columns depict the number of areas that were marked during the screen. Select the 1, 2 or 3 in the Load Level column after adding up the checked areas for each pattern.
2	1	and /or	0-3	
3	0	and /or	0-2	

SCORING

GOOD	MODERATE	POOR
17 - 21	11 - 16	7 - 10

7.8 Intake Demographic Form

Confidential

Intake Form

Complete this intake form to begin the UVM Nordic Ski study. Include your individual identification code given to you when you signed your consent form. You will need this to complete each monthly survey.

Thank you for participating in this Nordic Ski study.

Section 1 Confidential Athlete Information

Enter individual study identification code ______________________

Last name ______________________

First name ______________________

Date of Birth (use this format: 2 digit month-2 digit day-4 digit year) ______________________

Which gender do you identify with?
- ○ male
- ○ female
- ○ other

Are you right or left handed?
- ○ right
- ○ left

What is your height in centimeters? If you do not know, answer the next 2 questions, (i.e. enter "feet", then enter "inches" in the two separate boxes) ______________________

What is your height in feet? Use a whole number like 5 (eg. if you are 5 feet 10 inches tall, enter 5 in this box) ______________________

and now enter the "inches" part of your height Use a whole number. (eg if you are 5 feet 10 inches tall, enter 10 in this box) ______________________

What is your weight in kilograms? If you do not know, answer the next question. ______________________

What is your weight in pounds? ______________________

Please enter your email address to receive your monthly survey. ______________________

Please supply your cell phone number for alternate contact reminders about your monthly survey. Use the USA 10 digit format eg. (802) 123-1234 ______________________

Information about your skiing

What is your preferred nordic ski style? (choose all that apply)
- ☐ classic
- ☐ skate
- ☐ biathlon
- ☐ both classic and skate about equally

What is your dominant side in skate V1 technique?
- ○ right
- ○ left

In the 2013-2014 ski season what was your level of competition? ______________________

In the 2013-14 ski season what was your discipline?
- ☐ nordic skiing
- ☐ biathlon

How many years of nordic skiing experience do you have?	◯ 0 ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 ◯ 6 ◯ 7 ◯ 8 ◯ 9 ◯ 10 ◯ 11 ◯ 12 ◯ 13 ◯ 14 ◯ 15 ◯ 16 ◯ 17 ◯ 18 ◯ 19 ◯ 20 ◯ 21+
How old were you when you began competitive nordic skiing?	◯ 6 ◯ 7 ◯ 8 ◯ 9 ◯ 10 ◯ 11 ◯ 12 ◯ 13 ◯ 14 ◯ 15 ◯ 16 ◯ 17 ◯ 18 ◯ 19 ◯ 20 ◯ 21+
During the 2013-14 ski season, on average how many hours of on snow ski training did you participate in each week? (round up)	◯ 0-5 ◯ 6-10 ◯ 11-15 ◯ 16-20 ◯ 21-25 ◯ 26-30 ◯ 30+
Do you participate in other sports?	◯ Yes ◯ No
List the: name of the sport season/s or month/s you participate in this sport number of hours per week you practice/train for this sport More than one sport may be listed.	______________________________

Current Injuries

Do you currently have any injuries?	◯ Yes ◯ No

Select a body region (or regions) that best fits your current injuries.

- ☐ neck
- ☐ shoulder
- ☐ upper arm
- ☐ elbow
- ☐ forearm
- ☐ wrist & hand
- ☐ upper back
- ☐ mid back
- ☐ low back
- ☐ pelvis
- ☐ abdomen
- ☐ hip
- ☐ thigh
- ☐ knee
- ☐ lower leg
- ☐ ankle & foot

Describe your current injury. What does it feel like? __________________________________

Are you currently receiving treatment for your injury?

- ◯ Yes
- ◯ No

Describe the type of treatment you are receiving for your injury. Eg Physical Therapy, massage, Chiropractic, Exercise Therapy, medications .... __________________________________

Past Injury History

Have you EVER experienced any episodes of pain, ache or discomfort that lasted for longer than one week (7 days), or caused you to miss or modify any training or racing sessions?

- ◯ Yes
- ◯ No

Please list any previous injuries (including type of injury and date). __________________________________

Please list any previous surgeries (orthopaedic or not), include the year of the surgery. (if none, enter none in field) __________________________________

Current Medications

Please list any current medications you take (prescription and over the counter), use generic or brand name (whatever you can remember). (If no medications, please enter "none".) __________________________________

Women are you taking a contraceptive medication?

- ◯ Yes
- ◯ No

What is the name of the medication? __________________________________

What is the date of the first day of your last menstrual period? Use this format: 2 digit month-2 digit day-4 digit year. __________________________________

Occupation

What is your occupation?

- ☐ University student (NCAA athlete)
- ☐ Working full time (30+ hours per week)
- ☐ Working part time (less than 30 hours per week)
- ☐ Professional athlete

Please indicate major subject of study. ____________________

Please indicate average number of hours spent on academic work each week.

- ☐ 0-5
- ☐ 6-10
- ☐ 11-15
- ☐ 16-20
- ☐ 21-25
- ☐ 26-30
- ☐ 31-35
- ☐ 35-40
- ☐ 40+

What level of study are you in?

- ☐ undergraduate
- ☐ graduate

What is your job title? Describe your duties at work (eg sedentary, lifting and carrying, gardening, driving ....) ____________________

List the average hours per week you spend at your occupation (round up to whole hour)

- ☐ 0-5
- ☐ 6-10
- ☐ 11-15
- ☐ 16-20
- ☐ 21-25
- ☐ 26-30
- ☐ 31-35
- ☐ 36-40
- ☐ 40+

Please indicate activities your non training and racing hours are occupied with. ____________________

How many hours per week do you spend on these non skiing related activities?

- ☐ 0-5
- ☐ 6-10
- ☐ 11-15
- ☐ 16-20
- ☐ 21-25
- ☐ 26-30
- ☐ 31-35
- ☐ 36-40
- ☐ 40+

Emergency Contact Information

Emergency Contact Name ____________________

Relationship ____________________

Contact Phone number Use the USA 10 digit format eg. (802) 123-1234 ____________________

Consent to use this information

By signing this form I verify that the above information is correct and, when de-identified, can be used for research purposes. (type your first and last name) ______________________________

Date form completed. ______________________________

Please click "submit" to end the survey and submit your response.

7.9 Monthly Survey

Confidential

Monthly Survey

Please complete the monthly survey below.

Thank you for being part of this Nordic Ski study!

Section 1 Background Information

Enter individual study identification code (all 3 digits) ____________________

Has there been any change in the medications you are taking?
◯ Yes
◯ No

Please explain the medication change (eg a new medication, a stopped medication, a change in dose). ____________________

Has there been a change in your occupation since the last questionnaire?
◯ Yes
◯ No

Please describe your current occupation and the number of hours per week this occupies. ____________________

Women, what was the date of the first day of your last menstrual period? Use this format: 2 digit month-2 digit day-4 digit year ____________________

Training Questions.

Refer to your personal training diary to help answer the following questions.

How many "on snow" TRAINING sessions have you completed in the past month?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10
- ◯ 11
- ◯ 12
- ◯ 13
- ◯ 14
- ◯ 15
- ◯ 16
- ◯ 17
- ◯ 18
- ◯ 19
- ◯ 20
- ◯ 21
- ◯ 22
- ◯ 23
- ◯ 24
- ◯ 25
- ◯ 26
- ◯ 27
- ◯ 28
- ◯ 29
- ◯ 30
- ◯ 31
- ◯ 32+

Which skiing discipline have you predominantly been training for the past month?

- ☐ classic
- ☐ skate
- ☐ both about equally
- ☐ both, but classic more than skate
- ☐ both, but skate more than classic

On average how long did you spend "on snow" skiing per training session in the past month?

- ◯ 0-1 hours
- ◯ 1-2 hours
- ◯ 2-3 hours
- ◯ 3-4 hours
- ◯ 4-5 hours

What types of cross training have you used in the past month?

Indicate NUMBER of training sessions for any cross training discipline this month in table below (DURATION is of each session is asked in the next question).

Multiple cross training disciplines may be chosen.

	1-5	6-10	11-15	16-20	21-25	26-30	31+
Roller skiing	◯	◯	◯	◯	◯	◯	◯
Road cycling	◯	◯	◯	◯	◯	◯	◯
Mountain biking	◯	◯	◯	◯	◯	◯	◯
Stationary cycling	◯	◯	◯	◯	◯	◯	◯
Road running	◯	◯	◯	◯	◯	◯	◯

Trail running	○	○	○	○	○	○	○
Treadmill running	○	○	○	○	○	○	○
Rowing ergometer	○	○	○	○	○	○	○
Elliptical trainer	○	○	○	○	○	○	○
Weight lifting	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○

Describe your "other" cross training activity here. ______________________

In the table below, indicate the average workout DURATION (in hours) for each cross training discipline you used this month. (Round to whole hour).

Multiple disciplines may be chosen.

	1	2	3	4	5
Roller skiing	○	○	○	○	○
Road cycling	○	○	○	○	○
Mountain biking	○	○	○	○	○
Stationary bike riding	○	○	○	○	○
Road running	○	○	○	○	○
Trail running	○	○	○	○	○
Treadmill running	○	○	○	○	○
Rowing ergometer	○	○	○	○	○
Elliptical trainer	○	○	○	○	○
Weight training	○	○	○	○	○
Other	○	○	○	○	○

Racing Questions

Did you race this month?
- ○ Yes
- ○ No

What sport did you race in?
- ☐ roller ski
- ☐ classic ski
- ☐ skate ski
- ☐ biathlon
- ☐ road cycling
- ☐ mountain biking
- ☐ road running
- ☐ trail running
- ☐ rowing
- ☐ other

Describe the "other" sport you raced in this month. ______________________

How many races did you participate in this month?

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10
- ◯ 11+

Describe the type of race/s you participated in this month (eg 10km run, 50km classic ski race ...) ______________________________

Questions about NEW injuries this month.

In the past month have you experienced any NEW episodes of pain, ache or discomfort that lasted for longer than one week (7 days), or caused you to miss or modify any training or racing sessions.

- ◯ Yes
- ◯ No

Indicate where your new pain, ache or discomfort is/was felt.

- ☐ neck
- ☐ shoulder
- ☐ upper arm
- ☐ elbow
- ☐ forearm
- ☐ wrist & hand
- ☐ upper back
- ☐ mid back
- ☐ low back
- ☐ pelvis
- ☐ abdomen
- ☐ hip
- ☐ thigh
- ☐ knee
- ☐ lower leg
- ☐ ankle & foot
- ☐ other

Describe where your new pain is located. ______________________________

Describe the new injury/pain/discomfort you experienced this month. ______________________________

Is this injury the result of an ACCIDENT, TRAUMA or a FALL?

- ◯ Yes
- ◯ No

Describe the trauma/fall/accident that resulted in your injury. ______________________________

Have you been examined or treated for this new injury by a physician, physical therapist, athletic trainer or other health professional during the past month?

- ◯ Yes
- ◯ No

Name the type of health professional (not the person's name). Eg Physical Therapist, Osteopath, Medical Doctor .... ______________________________

How many days did this new pain last?

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10
- ◯ 11
- ◯ 12
- ◯ 13
- ◯ 14
- ◯ 15
- ◯ 16
- ◯ 17
- ◯ 18
- ◯ 19
- ◯ 20
- ◯ 21
- ◯ 22
- ◯ 23
- ◯ 24
- ◯ 25
- ◯ 26
- ◯ 27
- ◯ 28
- ◯ 29
- ◯ 30
- ◯ 31

Rate the intensity of this new pain at the time of completing this survey? no pain at all = 0 (left end of slider bar) worst pain ever = 100 (extreme right end of slider bar)

no pain at all ——— worst pain ever

(Place a mark on the scale above)

What is the worst level of this new pain you have experienced this month? no pain at all = 0 (left end of slider bar) worst pain ever = 100 (extreme right end of slider bar)

no pain at all ——— worst pain ever

(Place a mark on the scale above)

What is the least (lowest) level of this new pain you have experienced this month? no pain at all = 0 (left end of slider bar) worst pain ever = 100 (extreme right end of slider bar)

no pain at all ——— worst pain ever

(Place a mark on the scale above)

Questions about EXISTING or RECURRENT injuries this month.

In the past month have you experienced ANY episodes of pain, ache or discomfort that lasted for longer than one week (7 days), or caused you to MISS or MODIFY any TRAINING or RACING sessions? If you checked NO for "NEW" injuries above, please now consider recurring/ongoing/intermittent episodes of pain, ache or discomfort.	◯ No ◯ Yes, I missed or modified training for less than one week ◯ Yes, I missed or modified training for between 1 and 2 weeks ◯ Yes, I missed or modified training for between 2 and 3 weeks ◯ Yes, I missed or modified training for between 3 and 4 weeks ◯ Yes, I missed or modified training for the entire month since last completing this questionnaire
Describe where you felt pain, ache or discomfort (eg, low back, left shin, right shoulder ....)	☐ neck ☐ shoulder ☐ upper arm ☐ elbow ☐ forearm ☐ wrist & hand ☐ upper back ☐ mid back ☐ low back ☐ abdomen ☐ pelvis ☐ hip ☐ thigh ☐ knee ☐ lower leg ☐ ankle & foot ☐ other
Describe the location of your pain.	______________________________
Indicate your current level of pain (right now). no pain at all = 0 (left end of slider bar) worst pain ever = 100 (extreme right end of slider bar)	no pain at all — worst pain ever *(Place a mark on the scale above)*
Indicate your worst (highest) level of pain this month. no pain at all = 0 (left end of slider bar) worst pain ever = 100 (extreme right end of slider bar)	no pain at all — worst pain ever *(Place a mark on the scale above)*
Indicate your lowest level of pain this month. no pain at all = 0 (left end of slider bar) worst pain ever = 100 (extreme right end of slider bar)	no pain at all — worst pain ever *(Place a mark on the scale above)*

Did your injuries impact your TRAINING and RACING this month?

Consider TRAINING sessions only. This month, how many TRAINING sessions have you MISSED due to pain/injury?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10
- ◯ 11
- ◯ 12
- ◯ 13
- ◯ 14
- ◯ 15
- ◯ 16
- ◯ 17
- ◯ 18
- ◯ 19
- ◯ 20
- ◯ 21
- ◯ 22
- ◯ 23
- ◯ 24
- ◯ 25
- ◯ 26
- ◯ 27
- ◯ 28
- ◯ 29
- ◯ 30
- ◯ 31

Consider TRAINING sessions only. This month, how many TRAINING sessions have you MODIFIED due to pain/injury?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10
- ◯ 11
- ◯ 12
- ◯ 13
- ◯ 14
- ◯ 15
- ◯ 16
- ◯ 17
- ◯ 18
- ◯ 19
- ◯ 20
- ◯ 21
- ◯ 22
- ◯ 23
- ◯ 24
- ◯ 25
- ◯ 26
- ◯ 27
- ◯ 28
- ◯ 29
- ◯ 30
- ◯ 31

Consider RACING this month. This month, how many RACES have you MISSED due to pain/injury?

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10

Consider RACING this month. This month, how many RACES have you MODIFIED due to pain/injury? (eg opted for a shorter distance, did not use full effort ....)

- ◯ 0
- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8
- ◯ 9
- ◯ 10

Here is the LAST question this month!

Do you have any other comments this month? Thank you for completing this survey! ______________________________

7.10 MCS and Muscular Measures Data Entry File (Example)

		Muscular Measures						Squat - double leg	Primary (0= no problem present; 1=problem present)				Secondary				
Subject # study_id	participant_id	RIGHT hamstring length (degrees of hip flexion)	LEFT hamstring length (degrees of hip flexion)	Sorenson (secs)	McGill (secs)		Overall Score	Load level	Shoulders	Lumbar	Hips	Ankle/Feet	Head	Knees	Depth	Balance	Comments
1	5	85	80	148	360		12	1	0	1	1	1	1	1	1	1	elbows fw
2	1	90	80	182	214		13	2	0	1	0	0	0	0	0	0	LSP flex
3	3	75	75	204	360		14	3	0	0	0	0	0	0	0	0	wide stanc

The Lunge	Primary				Secondary					The Twist	Primary				Secondary				
Load Level	Balance	Lumbar	Hips	Ankles/Fee	Head	Knees	Depth	Comments		Load level	Shoulders	Lumbar	Hips	Ankle/feet	Head	Knees	Depth	Balance	Commnets
3	0	0	0	0	0	0	0	trailing knee touches		1	0	1	1	0	0	0	0	0	LSP side be
3	0	0	0	0	0	0	0	stable lunge		1	0	1	1	0	0	0	0	0	hips drop
3	0	0	0	0	0	0	0			1	0	1	1	0	0	1	0	0	hips drop,

The Bend	Primary				Seondary						The Pull	Primary				Secondary				Comments
Load Level	Shoulders	Lumbar	Hips	Depth	Head	Knees	Ankle/feet	Balance	Comments		Load level	Shoulders	Lumbar	Hips	Depth	Head	Knees	Ankle/feet	Balance	
2	0	1	0	0	0	0	0	0	LSP held in flexion thr		3	0	0	0	0	0	0	0	0	solid
1	1	1	0	0	0	0	0	0	lacks ful overhead rea		3	0	0	0	0	0	0	0	0	mo mvmt
2	0	1	0	0	0	0	0	0	LSP flex		3	0	0	0	0	0	0	0	0	no mvmt w

Push Up	Primary				Secondary						Single Leg Squat	Primary				Secondary				
Load level	Head	Shoulders	Lumbar	Depth	Hips	Knees	Ankle/feet	Balance	Commnets		Load level	Depth	Lumbar	Hips	Ankles/fee	Head	Shoulders	Knees	Balance	Commnets
1	0	1	0	1	0	0	0	0	CSP extension in push		1	1	1	1	0	1	1	1	1	L better th
2	0	0	0	1	0	0	0	0	lacks depth		1	1	1	1	0	0	0	0	0	LSP flex, hi
1	1	0	0	1	0	0	0	0	significant fwd head,		1	1	1	1	0	0	0	0	0	LSP flex, si

7.11 Correlation Output

Correlations

			Total_new_injuries_sum
Spearman's rho	past_injuries	Correlation Coefficient	.321*
		Sig. (2-tailed)	.041
		N	41
	age_began_competing	Correlation Coefficient	.175
		Sig. (2-tailed)	.273
		N	41
	other_sports	Correlation Coefficient	.140
		Sig. (2-tailed)	.383
		N	41
	Average monthly time on roller skis	Correlation Coefficient	.015
		Sig. (2-tailed)	.926
		N	40
	Average monthly time cycling	Correlation Coefficient	-.137
		Sig. (2-tailed)	.412
		N	38
	Average monthly time running	Correlation Coefficient	.278
		Sig. (2-tailed)	.083
		N	40
	Average monthly time using weights	Correlation Coefficient	.059
		Sig. (2-tailed)	.726
		N	38

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations

			Total_new_injuries_sum
Spearman's rho	age	Correlation Coefficient	.122
		Sig. (2-tailed)	.447
		N	41
	BMI	Correlation Coefficient	-.124
		Sig. (2-tailed)	.438
		N	41
	male	Correlation Coefficient	.073
		Sig. (2-tailed)	.649
		N	41
	years_of_competition	Correlation Coefficient	-.098
		Sig. (2-tailed)	.541
		N	41
	trunk_ratio_SM	Correlation Coefficient	.006
		Sig. (2-tailed)	.970
		N	40
	trunk_ratio_MS	Correlation Coefficient	-.006
		Sig. (2-tailed)	.970
		N	40
	Sorenson180	Correlation Coefficient	-.007
		Sig. (2-tailed)	.965
		N	40
	RIGHThamstringlengthdegreesofhipflexion	Correlation Coefficient	-.220
		Sig. (2-tailed)	.167
		N	41
	LEFThamstringlengthdegreesofhipflexion	Correlation Coefficient	-.147
		Sig. (2-tailed)	.361
		N	41
	McGillsecs	Correlation Coefficient	-.027
		Sig. (2-tailed)	.865
		N	41
	MCSOverallScore	Correlation Coefficient	-.077
		Sig. (2-tailed)	.632
		N	41
	weights_mean	Correlation Coefficient	.059
		Sig. (2-tailed)	.726
		N	38

Correlations

			Total_new_injuries_sum
	Total_cross_training_time_mean	Correlation Coefficient	.168
		Sig. (2-tailed)	.293
		N	41
	Total_snow_training_time_mean	Correlation Coefficient	.052
		Sig. (2-tailed)	.746
		N	41
	Total_training_time_mean	Correlation Coefficient	.166
		Sig. (2-tailed)	.300
		N	41
	training_lost_to_injury_mean	Correlation Coefficient	.167
		Sig. (2-tailed)	.445
		N	23