The Effect of a Modified Nordic Curl Intervention on Prevalence of Hamstrings Injuries in A Professional Football Team

By

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ABSTRACT

There are many discussions about the occurrence of hamstring injury, especially in running dominant sports such as Canadian rules football. Many interventions exist to decrease the risk and/or occurrence of hamstring injury, with the Nordic Curl being among one of the most studied interventions. The Nordic Curl is commonly implemented as part of a preventative injury program, often alongside various other methods of injury prevention exercises. Limited research exists on the implementation of a "more difficult" variation of the conventional Nordic Curl, which involves keeping the concentric portion in the exercise, as opposed to only completing the eccentric portion. This modified Nordic Curl (mNC) exercise was completed in one professional football team over the duration of four competitive seasons, post practice in a progressive manner to an upper limit of 5 reps per practice. Hamstring injury data collected during the four years of implementing the mNC was compared to the prior four years of hamstring injury data in three categories: rate of hamstring injuries per 4 years; average calendar days lost due to injury; and a comparison of total hamstring injuries per timeframe of the season. Independent t-tests were calculated to analyze for differences between rate of hamstring injuries in the two time periods (intervention vs non-intervention), and average time lost due to hamstring injury between the two time periods. Four Mann Whitney U tests were conducted to examine temporal differences in number of injuries between the intervention and non-intervention periods using four separate timeframes within the competitive season. No significant differences were found with any analyses, but large effect sizes were observed for differences between the groups for rate of hamstring injuries and the number of injuries that occurred in the first 6 weeks of the season. The results suggest the mNC does not significantly affect hamstring injury rates, time lost due to injury or specific timeframes within the competitive season. Future research should seek to investigate the modified version of the Nordic curl's electromyographical output, as well as further study using a larger sample size than the current study.

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TABLE OF CONTENT

CHAPTER 1 – SCIENTIFIC FRAMEWORK

1.1 Introduction

Gridiron football has the highest injury rate in games and practices when compared with 14 other National Collegiate Athletic Association (NCAA) sports (Hootman, Dick, & Agel, 2007). The time-loss injury rate for NCAA football games averaged 36 injuries per 1000 athlete-exposures (one athlete participating in one practice or game) (Dick et al., 2008). With increased competition and physical strain, some injuries are more predominant than others. In a recent study of professional football in Canada, joint and ligament injuries were the most common, followed by muscle and/or tendon injuries (Robbins et al., 2020). The Canadian Football League (CFL) is Canada's professional gridiron football league consisting of nine teams spread across the country. Football is a running and collision-based sport. Sports where there is a high running demand placed on athletes tend to display a higher incidence of hamstring injury when compared with sports that do not require a large running component (Opar, Williams, & Shield, 2012). The hamstrings muscle group (semitendinosus, semimembranosus, and biceps femoris) is a highly injured area in gridiron football (Lamplot & Matava, 2016). Evidence suggests that the hamstring muscles are most vulnerable to injury during the rapid change from eccentric to concentric muscle actions, such as occurs when the leg decelerates to strike the ground during running (terminal swing phase) (Bourne et al., 2018; Hegyi et al., 2019; Iga, Fruer, Deighan, Croix, & James, 2012; Ribeiro-Alvares, Marques, Vaz, & Baroni, 2018; Verrall, 2001).

Many interventions exist that aim to decrease the incidence of hamstring muscles injury, generally through eccentric strength training and emphasizing proper running mechanics (Bourne et al., 2018). One common method to reduce the risk of hamstrings injury is through the Nordic hamstring curl exercise. The Nordic hamstring curl (NC) has been supported as a method for hamstring injury prevention in running-based sports (Bourne et al., 2018; Iga et al., 2012; Ribeiro-Alvares et al., 2018) and seems to improve running speed, change of direction speed, and hamstring muscles strength more so than not completing the NC (Siddle et al., 2019). The lack of equipment needed and difficulty of the exercise make it a popular exercise to isolate hamstring muscles activation (Bourne et al., 2017). To complete a conventional NC, one kneels on the ground with the hips in full extension, and with the help of a teammate or a brace holding the lower legs in contact with the ground, the torso is slowly lowered anteriorly to the ground (Goldman & Jones, 2007).

Conventional NCs are suggested to be effective in reducing hamstring strains due to the eccentric lengthening of the hamstring muscle group, to a point where tension cannot be maintained any longer and the person touches the ground with their torso (Bourne et al., 2018). In one intervention conducted over the course of two seasons of English Premiership rugby union, 12 teams reported the occurrence of all hamstring muscle injuries, and included three different intervention conditions of: strengthening; strengthening and static stretching; and strengthening, stretching and Nordic hamstring exercises (Brooks, Fuller, Kemp, & Reddin, 2006). The researchers found the group using all three interventions (strengthening, stretching and Nordics) had a significantly lower incidence of injury compared to the strengthening alone group. This group also had a reduced severity of injury indicated by a reduction in playing time lost due to injury (Brooks et al., 2006).

In the above-mentioned study, when performing the NC, the athletes were instructed to lower their trunks as far as possible to the ground while maintaining tension, and then fall to the ground when tension could not be maintained any longer. It is suggested that the Nordic exercise is effective because it increases the angle of peak torque, increases peak eccentric hamstring torque and decreases the quadricep to hamstring strength ratio (Bourne et al., 2018; Delextrat et al., 2020; Ribeiro-Alvares et al., 2018).

Most interventional studies that examine the Nordic curl are geared towards short-term changes in hamstring injury incidence or strength and are limited by compliance to the protocol being implemented (i.e., not completing extra Nordic curl sessions or ceasing Nordic interventions due to complaints of muscle soreness) (Chebbi, Chamari, Van Dyk, Gabbett, & Tabben, 2020; Van Der Horst, Smits, Petersen, Goedhart, & Backx, 2015). Thus, researchers must aim to make changes as quickly as possible, while also limiting muscle soreness, which is often the main reason to exclude the concentric portion of the exercise. However, when the intervention can be scaled throughout an 18-week season, the increase in volume of reps can be smaller (+1 per 6 weeks), and thus produce less muscle soreness as a result of completing the concentric portion with less reps (2-5 reps per practice) than most other interventions that are completed.

With all of the above-mentioned variables in mind, one CFL team decided to implement a “modified” version of the conventional Nordic curl as a way to reduce risk of hamstring injuries. Hamstring injuries were specifically chosen as a target as this injury was the most common site of soft tissue injury in the years leading up to the implementation of the modified Nordic curl intervention. To complete the modified version of the Nordic curl, the torso was lowered to a point where the player felt they could no longer continue to extend their knees and control their torso descent, when they then concentrically contracted the hamstring muscles to return to the starting upright position. This method was used due to the possibility of "cheating" conventional NCs, and not maintaining tension to the very last point possible. The concentric portion also added more time under tension, compared to only the time under tension from the eccentric portion. It was noted prior to the beginning of the Nordic intervention, some athletes would minimally engage their hamstrings to limit the descent and essentially free fall anteriorly, in an attempt to "cheat" the exercise and limit muscular strain. With the added concentric portion, the athlete at minimum, must contract with enough torque to return to the starting position. The brief isometric contraction occurring between the eccentric lowering portion and the concentric rising portion of the exercise make this variation very difficult to perform. The players in the intervention period began each season completing 2 modified Nordic Curls (mNC) at the end of every practice for the duration of pre-season (4 weeks), which was then increased to 3 repetitions at the end of every practice until the end of 6th week of the season. For weeks 7 through 12, reps were increased to 4 per session. At this point the repetitions were increased to 5 at the end of every practice until the end of the season (weeks 12-18 plus playoffs). One team in the CFL implemented the mNC exercise (as described in the intervention above) after every practice throughout the playing season for 4 years in an attempt to reduce the hamstrings injury rate in their athletes.

The purpose of this retrospective study was to evaluate if there are any differences in hamstring muscles injury rates, injury severity, and timeframe comparisons of injuries in one CFL team when retrospectively comparing injury data during the 4-year intervention period (using the mNC) and the 4 years previous to implementing the intervention in the same CFL team.

1.2 Review of Literature

1.2.1 Strength Development and Hamstring Injury

Recent epidemiological studies have shown that football has the highest injury rate of any team sport in the United States at the high school level and the university level (Elliott, Zarins, Powell, & Kenyon, 2011; Hootman et al., 2007). In professional football, according to Feeley et al (2008), muscle strains accounted for 46% of practice injuries and 22% of preseason injuries over a 10-year study of NFL preseasons. Hamstring injuries were the second most common preseason injury. This trend of elevated orthopedic injuries compared to other sports is similar in the Canadian Football League (CFL). In a recent study of eight CFL seasons investigating epidemiological injury statistics, joint/ligament injuries were the most common and muscle/tendon injuries were the second most common (Robbins et al., 2020). Among the muscle/tendon injuries, hip, groin and thigh were the most commonly injured areas (Robbins et al., 2020). These highly injured areas have been the object of study in modern strength training literature, aiming to decrease these types of injury. Researchers have investigated the effect of strength training on injury, in particular soft tissue injury(Suchomel, Nimphius, & Stone, 2016).

The high incidence rate of soft tissue injuries have been shown to be decreased to less than one-third and overuse injuries reduced by nearly 50% in response to resistance training interventions (Fleck & Falkel, 1986; Lauersen, Bertelsen, & Andersen, 2014; Suchomel et al., 2016). Potential mechanisms responsible for the decreased injuries may occur through increases in the structural strength of ligaments, tendons, joint cartilage and connective tissue sheaths within muscles (Fleck & Falkel, 1986; Lauersen et al., 2014; Suchomel et al., 2016). As mentioned earlier, hamstring injuries are among the most common soft tissue injury in running based sports, and have been examined in sport science literature due in part to the ability to decrease their incidence through better training methods (Opar et al., 2012).

Hamstring muscles are suggested to be at a higher risk of strain injury during high speed sprinting in part due to the biarticular attachment of the muscle, as it may be elongated by either extending the knee or flexing the hip, or both (Croisier, Ganteaume, Binet, Genty, & Ferret, 2008). It is this eccentric muscle contraction (hip flexion paired with knee extension) that has been shown to be the source of the most muscle fiber damage and soreness, potentially inducing micro-tears of the sarcomeres, and if repeated enough without adequate recovery, may cause myocyte cell death and change the length-tension relationship of the muscle (Brockett, Morgan, & Proske, 2001; Cheung, Hume, & Maxwell, 2003; Lewis, Ruby, & Bush-Joseph, 2012; Orishimo & McHugh, 2015). This eccentric lengthening of the hamstring muscle group is most pronounced during the terminal swing phase of running, in which the hip is flexed and the knee joint is decelerating extension, and as well in the early stance phase of running in which the hip is being actively extended (Guex, Lugrin, Borloz, & Millet, 2016; Schache, Dorn, Blanch, Brown, & Pandy, 2012). While the biomechanics of sprinting may be enhanced to optimize performance to a degree, resistance training with injury prevention in mind may further reduce the risk factors related to hamstring injuries.

Risk factors for hamstring muscle injuries may be classified as alterable/unalterable or as modifiable/non-modifiable. Unalterable/non-modifiable risk factors commonly include, increasing age, ethnicity and previous hamstring injury (Opar et al., 2012). Previous injury of any anatomical location is often cited as the highest risk factor to re-injury (Elliott et al., 2011), where maladaptation's such as non-functional scar tissue, reduced flexibility, altered biomechanics and reduced eccentric strength all potentially contribute to re-injury (Opar et al., 2012). Modifiable risk factors that may be altered as a result of eccentric based resistance training commonly include: hamstring to quadriceps strength ratio, muscular fatigue and eccentric hamstring strength (Bourne et al., 2018; Brooks et al., 2006; Opar et al., 2012).

1.2.2 Hamstrings to Quadriceps Ratio

The relationship between the strength of the knee flexors and knee extensors has been shown to play a crucial role in knee joint stability and lower limb injury (Ruas et al., 2019). This relationship is important when assessing risk of hamstring injury, as imbalances in strength between knee flexion and knee extension, specifically a reduction in eccentric hamstring strength when compared to concentric quadriceps strength has been suggested to increase risk of hamstring injury (Green, Bourne, & Pizzari, 2018; Ruas et al., 2019). The knee extensors (primarily quadriceps) are main drivers in propulsion during running and jumping activities, while the knee flexors serve to stabilize the knee during running and landing movements by decelerating the lower limb in an eccentric fashion (Stastny, Lehnert, & Tufano, 2018). The most commonly reported strength assessment in the lower limbs used in the past is the conventional ratio. This method compares concentric peak torque of the hamstrings (knee flexors) to the concentric peak torque of the quadriceps (knee extensors), typically at 60 degrees per second, with no specified point in range of motion (Coombs & Garbutt, 2002; Green et al., 2018; Heiser, Weber, Sullivan, Clare, & Jacobs, 1984). This method was suggested to provide normative data to reduce hamstring injury occurrence (Heiser et al., 1984). The initial ratio reported by Steindler (1955) proposed the generalization that knee extension force should be greater than knee flexion force by a magnitude of 3:2 or 1.5 (Coombs & Garbutt, 2002). This ratio is less supported in recent studies, as concentric actions never occur simultaneously in opposing muscles, thus a relative strength comparison between the action of the eccentric knee flexors and concentric knee extensors is considered more applicable (Coombs & Garbutt, 2002; Holcomb, Rubley, Lee, & Guadagnoli, 2007; Stastny et al., 2018). This “functional” ratio changes in value throughout range of motion at the knee and at different angular velocities, but a value of roughly 1.0 is considered ideal (Coombs & Garbutt, 2002; Delextrat et al., 2020; Holcomb et al., 2007). This value indicates the eccentrically acting hamstrings have the ability to fully brake the action of the concentrically acting quadriceps during fast knee extensions (60-240 degrees/second) from 90 degrees to terminal knee extension (Coombs & Garbutt, 2002). High speed running also requires the hamstrings to eccentrically brake the lower leg before terminal knee extension, which further adds to the credibility of the functional ratio compared to the conventional ratio (Coombs & Garbutt, 2002). This ratio also monitors fatigue in the hamstrings and quadriceps in the same fashion that they would fatigue during repeated bouts of sprinting, rather than concentrically taxing both the hamstrings and the quadriceps, as would be seen in the conventional ratio (Coombs & Garbutt, 2002). As fatigue begins to accumulate in the knee flexors and extensors, altered biomechanics of high velocity sprinting takes place, including decreased hip flexion and increased knee extension during the swing phase of the sprinting stride (Pinniger, Steele, & Groeller, 2000). When considering lower body injury prevention methods, specifically hamstring injury prevention, it is important to consider how the hamstrings and quadriceps are being loaded (eccentrically/concentrically), to what extent each group is being developed, and to what level fatigue is being induced. Local muscular endurance of the hamstring muscle group is also essential to a well-developed injury prevention plan, that manages acute fatigue, while also raising the level of endurance in the long term.

1.2.3 Fatigue

Muscular fatigue may be defined as a decrease in maximal force or power production in response to contractile activity (Wan, Qin, Wang, Sun, & Liu, 2017). Fatigue can be further divided into central, meaning it originates at the central nervous system and, as a result, the neural output to the muscle is decreased. Muscular fatigue can also be peripheral, meaning the fatigue is produced by changes at or distal to the neuromuscular junction (Wan et al., 2017).

Fatigue and hamstring injury are a common topic of interest in research, as it has been shown that electromyographic (EMG) activity is increased during multiple sets of resistance training, to a point of failure (Marshall, Lovell, Knox, Brennan, & Siegler, 2015). When the lower limb muscles reach a point of fatigue, altered biomechanics are shown, as illustrated by Pinniger et al. (2000). The authors had 12 male Australian football players complete three 40-meter sprints and obtained kinematic and EMG data in the non-fatigued condition, then they completed a hamstring fatiguing protocol and repeated the sprints. In the fatigued state, kinematic analysis revealed thigh and knee flexion were decreased and an increased knee extension angle compared to the non-fatigued state was seen. This resulted in a longer swing phase and a larger thigh extension angle when compared to the non-fatigued state. The authors suggest this pattern of greater knee extension angle in the fatigued state could result from fatigued hamstrings being unable to eccentrically decelerate the lower limb, resulting in the longer swing time. This pattern was corroborated in the EMG activity, showing an earlier cessation of the rectus femoris and an earlier onset of semitendinosus and biceps femoris, putting more stress on the posterior aspect of the thigh in the fatigued condition (Pinniger et al., 2000). This alteration in biomechanics and EMG activity in a fatigued state suggests the hamstrings are more vulnerable to injury as they are placed under higher load as fatigue begins to accumulate in the lower body.

Fatigue as an injury risk factor can further be extrapolated from the local muscle to the whole system, as a function of load or stress on the body. Load or stress must be managed properly when attempting to reduce injury risk factors in sport (Gabbett, Whyte, Hartwig, Wescombe, & Naughton, 2014). Periodized training models attempt to manage applied stress, through periods of higher intensity training, paired with periods of lower intensity (Windt & Gabbett, 2017). Two theories have been proposed that provide the basis for periodization: the General Adaptation Syndrome (GAS), and the fitness-fatigue paradigm (Selye, 1950; Zatsiorsky & Kraemer, 2006). The former was the original basis for periodization of training practices (although it was initially intended to explain illness, not physical fitness training), stating that the response to a stressor begins with an initial alarm reaction, followed by a reduction of function, and if continued, exhaustion or death will occur (Haff & Triplett, 2016; Selye, 1950). If the stressor is reduced, an increase in resistance to the stress above the previous baseline function may be seen and is referred to as adaptation (Haff & Triplett, 2016; Selye, 1950). The GAS theory served as the basis for the fitness-fatigue paradigm, that attempts to incorporate the state of fitness of an individual, and the current level of fatigue generated from training, into a level of preparedness (Gabbett et al., 2014). This paradigm lead to the introduction of the use of global positioning systems (GPS) to quantify distances ran during a session, in an attempt to manage the fitness and fatigue of athletes, and ultimately increase preparedness (Aughey, 2011).

1.2.4 Workload

Global Positioning Systems (GPS) consist of an array of satellites and receivers, to calculate distance travelled in a period of time, among other more nuanced velocity metrics (Scott, Scott, & Kelly, 2016). GPS units have been used in the sporting context since 1997 and have since increased in complexity in regards to how performance data is collected and analyzed (Scott et al., 2016). Prior to the introduction of GPS to sport, Calvert et al. (1976) suggested a performance model that quantified the balance between the chronic training load (fitness) and the acute training load (fatigue) using arbitrary units of training to mathematically come up with an athlete's "workload" or amount of total stress imposed on the system as a whole. This initial model was elaborated on by Gabbett et al. (2014) as "the workload being a quantification of the demands imposed on an athlete during one or more matches or training sessions". A player's workload can further be used to estimate an index of athlete preparedness through a model coined the "acute to chronic workload ratio (ACWR)". The ACWR is based on the model presented by Calvert et al. (1976), that takes the current workload (acute 7-day workload) and the workload that an athlete has experienced (chronic 28-day workload) and uses the ratio to estimate performance and quantify injury likelihood (Gabbett, 2016; Hulin, Gabbett, Caputi, Lawson, & Sampson, 2016; Murray, Gabbett, Townshend, & Blanch, 2017). For example, if an athlete runs for 1 kilometre every day (7 days) for 4 weeks of practices, his chronic workload (fitness) is the average of these 28 days (1 kilometre). If this athlete were then to run for 3 kilometres every day the next week, his acute workload would now average 3 kilometres and would be 3 times as high as the chronic workload. The acute to chronic workload ratio would then be equal to the average of the acute workload (3) divided by the average chronic workload (1). The most common units used to calculate ACWR are total distance covered per session and total distance covered at a high speed (arbitrary velocity) per session. The prediction of injury likelihood through the ACWR has been studied in recent years, and the main findings consistent through the literature have been twofold. First, large spikes (>1.5) in acute workload are significantly related to injury in both the week the elevated spike is seen, as well as the following week, and second, high chronic workloads may offer a protective mechanism to injury (Gabbett, 2004; Hulin et al., 2016; Windt & Gabbett, 2017).

Incidence of injury and corresponding spikes in acute workloads were shown in a recent study of 59 elite Australian football players, over the course of 2 years, in which GPS sensors were used to track total distance in meters covered per session (game or practice) of players and non-contact time-loss injuries. A total of 40 injuries were sustained over the 2-year period, of which the hamstrings were the most injured site (53%). Using total distance covered in meters (taken from GPS player measurements), players who exceeded an ACWR of >2.0 were 5-21 times more likely to be injured than players who did not exceed an ACWR of 1.5 (Murray et al., 2017).

Injuries relating to workload volumes was also a part of a study investigating the effect of three groups within professional Rugby Union play over the course of two seasons. Groups of strengthening, strengthening and static stretching, and strengthening, static stretching and NCs were all assessed over two seasons according to the rate and severity of hamstring injury. In relation to training volumes, the chance of at least one player from the 11 clubs sustaining a major hamstring injury (>3 weeks time lost) was significantly increased when very high volumes (>12.5 hours per week) were performed in the preceding week (Brooks et al., 2006).

Being cognizant of acute stress is important to consider when planning short and long term adaptations, as being underprepared for a stressor is just as hazardous as being over-trained/stressed (Bourdon et al., 2017; Gabbett, 2010; Gabbett & Ullah, 2012). The same can be said for strength adaptations, as they should also be introduced gradually to avoid overtraining and creating excess soreness in-season, especially when dealing with eccentric emphasized training.

1.2.5 Eccentric Strengthening

An eccentric muscle action occurs when a muscle lengthens under tension and slows a movement. An example of this would be to lower a weight in your hand, moving from elbow flexion to elbow extension. The biceps group is acting eccentrically to control the descent of the weight to limit injury to the elbow joint. In sprinting, the hamstrings function eccentrically to slow the extension of the lower limb. Due to the high rate of injury to the hamstring group, particularly during the terminal swing phase of the sprinting stride, research has examined ways in which this rate of injury can be curbed or decreased (Guex et al., 2016; Schache et al., 2012). Eccentric training may be an effective prophylactic training modality due to its potential effect of increasing peak muscular torque at longer muscle lengths (Bourne et al., 2018). During eccentric contraction, some sarcomeres are stretched to the point that they become disrupted and as these contractions are continued, the areas of disruption grow (micro-tearing), leading to some cells dying (Iga et al., 2012). The longitudinal addition of sarcomeres is thought to be the mechanism by which eccentric training may shift the length-tension relationship towards peak torque output at longer muscle lengths, although this has yet to be fully elucidated in humans (Brockett et al., 2001; Kilgallon, Donnelly, & Shafat, 2007; Tyler, Schmitt, Nicholas, & McHugh, 2017). Longer muscle fiber lengths allow the muscle to be elongated further and with greater tension before macro damage (full-tearing) occurs, and decreases the micro damage, felt as delayed-onset muscle soreness (DOMS) (Brockett et al., 2001; Kilgallon et al., 2007; Tyler et al., 2017). It has also been proposed that a shift in the angle of eccentric peak torque (APT) (in the hamstrings) toward longer muscle lengths, usually achieved with eccentric strength training, may contribute to decreased (hamstring) injury risk (Delextrat et al., 2020). These physiological and biomechanical changes have been shown to occur with eccentric based training, with NCs being used as the most common method of intervention based on previous research support and the ease of implementation (Brockett et al., 2001; Delahunt, McGroarty, De Vito, & Ditroilo, 2016; Iga et al., 2012).

The NC as first suggested by Brockett et al. (2001), was developed to target eccentric strengthening of the hamstrings with little to no equipment required. To complete a conventional NC, one kneels on the ground with the hips in full extension, and with the help of a teammate or a brace holding the lower leg in contact with the ground, the torso is slowly lowered anteriorly to the ground (Goldman & Jones, 2007). NCs have been shown to improve overall eccentric hamstring torque, decrease asymmetries between limbs, improve hamstring-to-quadricep ratio, increase the angle of eccentric peak torque, leading to longer muscle lengths and reduced incidence of hamstring injuries in a variety of sports (Brockett et al., 2001; Croisier et al., 2008; Delahunt et al., 2016; Delextrat et al., 2020; Hegyi et al., 2019; Iga et al., 2012; Marshall et al., 2015; Petersen, Thorborg, Nielsen, Budtz-Jørgensen, & Hölmich, 2011; Ribeiro-Alvares et al., 2018; Van Der Horst et al., 2015). NCs have been shown to activate the biceps femoris and semitendinosus muscles to a greater extent than 9 other comparable hamstring exercises during eccentric contractions, which is useful for rehabilitation professionals seeking to target either the biceps femoris (most commonly injured muscle of hamstrings) or the medial hamstrings (Bourne et al., 2017). Large scale interventions have been carried out to investigate the effect of a NC intervention on hamstrings injury incidence (Opar et al., 2012). One study by Van Der Horst et al. (2015), demonstrated a significant reduction in hamstring injuries in 292 male amateur soccer players completing a Nordic hamstring protocol over a 13-week period, with a follow up of one year, when compared to an equal control group that did not complete the protocol. In a more recent study investigating the effect of a NC graded intervention program, one professional soccer team was followed for 5 seasons, in which the first and last season, no intervention was used, to serve as a control (Chebbi et al., 2020). In total, 116 players were studied over the course of 5 seasons. The intervention seasons consisted of "+10 weeks" of a gradually increasing set and rep scheme of Nordics, up to a maximum of 3 weekly sessions of 3 sets of 12, 10, and 8 repetitions, after which a maintenance period was followed for the remainder of the season, consisting of 1 session of 3 sets of the same repetition scheme (Chebbi et al., 2020). Players were not mandated to participate, and thus some performed more sessions than others, resulting in 3 groups formed based on participation in the Nordic sessions. The highest risk of hamstring injury was reported in the low participation group with an odds ratio of 1.77 injuries per 1000 hours of training exposure (Chebbi et al., 2020).

This research provides evidence as to the efficacy of the NC in decreasing hamstring injury risk via the above listed potential mechanisms. One area commonly discussed in research within team settings are the limitations regarding the compliance of the athletes to the Nordic protocol. The most common protocol involves asking athletes to perform 1-3 sessions of 1-3 sets of 6-12 reps of Nordics, on top of their current training requirements (Petersen et al., 2011). The justification of this training scheme may be to ensure a positive training effect for a shorter duration of time (although this is not always the case). While in theory this may make sense, having athletes complete additional work, separate from their regular training regimen is often met with resistance, from players and coaches alike. A potential solution to the problem of compliance is to reduce the daily requirement of reps completed but increase the frequency in which the exercise is completed from 1-3 times per week, to every day of practice. In this way the athletes are not required to perform much extra work daily, but the aggregate volume of work roughly equates to the 1-3 sessions over longer time frames (18-24 weeks).

1.2.6 Statement of the Problem

To date, no studies have investigated the effect of a modified Nordic curl preventative program on hamstring strain injuries within the same Canadian professional football team over multiple seasons. Therefore, the objective of this study was to retrospectively analyze hamstring injury data collected during four years of implementing the mNC to the prior four years in three categories: overall rate of hamstring injuries; average days lost due to injury, and a comparison of total hamstring injuries per timeframe of the season. Independent t-tests were calculated to analyze for differences between rate of hamstring injuries in the two time periods (intervention vs non-intervention), and average time lost due to hamstring injury was calculated to provide a measure of hamstring injury severity according to days lost. Four Mann Whitney U tests were conducted to examine temporal differences in number of injuries between the intervention and non-intervention periods using four separate timeframes within the competitive season. This information will support or refute the use of a modified Nordic curl intervention to curb hamstring injury rates and time loss due to hamstring injury.

1.2.7 Hypotheses

The main hypothesis of this study is the average rate of reported hamstring injuries will be lower in the 4-year period of conducting mNCs versus the 4-year period prior to using the mNC intervention in one CFL professional team. The second hypothesis of this study is that there will be a **r**eduction in the average calendar days missed per hamstring injury, from initial hamstring injury to return to play in the 4-year period of conducting the mNC versus the 4-year period prior to using the mNC. The third hypothesis of this study is that there will be a reduction in the number of hamstring injuries in the last third of the season in the 4-year period of conducting mNC versus the last third of the season during the 4-year period prior to using mNC.

CHAPTER 2 - METHODS

2.1 Experimental Design

The current study used a secondary retrospective analysis, where the rate of reported hamstring injuries, calendar days missed due to hamstring injury, and when the hamstring injuries occurred during the season were analyzed. A hamstring injury was defined as any muscle strain injury to the posterior thigh resulting in a minimum 2 days of lost participation from either practices or games (Elliott et al., 2011). Timeframes of the season were divided as follows: pre-season, weeks 1 through 6, weeks 7 through 12, and weeks 13 through 18.

2.2 Participant Characteristics

A total of 906 players were signed to a minimum of at least 1 day of active participation and completed a medical examination with the one CFL team from the period of the start of 2012 to the end of the 2019 season. The ages of athletes in this period varied from 20 to 39 years old and heights and weights also varied. A total of 87 hamstring injuries were sustained in the 8-year period from 2012-2019, of which 74 were used for analysis. Two injuries from the pre-intervention period (2012-2015), and 11 from the intervention period (2016-2019) were not included in the final analysis because these players were released from the team after they sustained the injury, and thus did not have data related to time missed due to injury. Inclusion of these players would skew the average calendar days missed due to injury to a lower average as these players would account for zero days missed. An argument could be made to include these 13 players in the final analysis using averages of time missed due to injury, but the large variability seen in return to play times make this inclusion of data irresponsible. While the standard deviation shown in this study of average time lost is not substantial in size, hamstring injuries in training camp are anecdotally suggestive of poor levels of preparation in the offseason. When baseline levels of overall fitness are low, the potential for much longer return to play times are greater, as more time must be spent improving the players general physical fitness levels, in addition to the hamstring rehabilitation (Buckthorpe, Gimpel, Wright, Sturdy, & Stride, 2018).

2.3 Outcomes

The rate of hamstring injuries per year, grouped as 4-year periods (pre-intervention versus intervention) were compared using independent t tests. Comparisons of severity were made by comparing average days lost per injury in the 4-year period of no mNC versus the 4-

year period of completing the mNC. Comparisons of temporal aspects of hamstring injuries were investigated, seeking to compare when hamstring injury rate was highest during the season and if the mNC had any effect in any timeframe of the season when compared to the same timeframe from the non-mNC period using the non-parametric Mann-Whitney U test of unpaired groups.

2.4 Intervention

For the intervention group, all healthy players were asked to complete a prescribed number of mNCs with a teammate at the end of every practice day. In the mNC, the torso was lowered to a point where the individual player felt they could not extend past, and then they concentrically contracted the hamstring muscles to return to the starting upright position. This modification to the traditional NC was used to increase time under tension of the hamstrings, as well as to limit the possibility of "cheating" conventional NCs and not maintaining tension to the very last point possible, thus reducing tension on the hamstring muscle group. The players in the 4-year intervention period began each season completing 2 mNCs at the end of every practice for the duration of pre-season (4 weeks), which was then increased to 3 repetitions at the end of every practice until the 6th week of the season. For weeks 7 through 12, reps were increased to 4 per session. After this point the repetitions were increased to 5 at the end of every practice until the end of the season (weeks 12-18 plus playoffs). No additional hamstring prevention programs were implemented in the non-intervention years.

2.5 Statistical Analysis

Statistical analysis was conducted with Statistica software (Tibco Statistica 13.3, TIBCO Software Inc., 3307 Hillview Avenue, Palo Alto, CA, U.S.A.). The objective of the first analysis was to compare hamstring injuries in both time periods to see if the mNC decreased the average amount of hamstring injuries recorded. The objective of the second analysis was to compare the severity of time lost due to hamstring injury, per injury. The objective of the third hypothesis was to determine if there were any differences between the intervention period and non-intervention in overall rates of hamstring injury rates among 4 separate timeframes of the season (pre-season, week 1-6, week 7-12, week 13-18).

Investigated variables were: hamstring injuries per year, calendar days lost per injury per year, and hamstring injuries occurring within each timeframe of the season, divided as pre-season, weeks 1 through 6, weeks 7 through 12, and weeks 13 through 18. Data were tested for normality by the Shapiro-Wilk W test and for equal variances with Levene's test. Two separate independent t-tests were used to compare the intervention years with the non-intervention years for: 1) 4-year average of hamstring injury rate; and 2) 4-year average days lost per injury. As Levene's test yielded significant results, the non-parametric Mann-Whitney U test of unpaired groups was used to determine if there were statistically significant differences in the number of hamstring injuries in each timeframe of the season (as listed above), when compared to the corresponding same timeframe in the non-intervention period. The four timeframes of pre-season, weeks 1 through 6, weeks 7 through 12, and weeks 13 through 18 were each compared from the intervention period to the non-intervention period to investigate if a statistical difference would be found at any interval of the season. An alpha level of $p \leq 0.05$ was considered statistically significant. Effect sizes were also used to determine intervention effectiveness. Effect sizes were calculated and included in this study because they complement hypothesis testing by estimating the size of the treatment effect (Fritz, Morris, & Richler, 2012). Effect size reporting provides quantification of the observed effect without the misleading inclusion of very large or very small sample sizes (Rhea, 2004). For example, as sample size increases in a study, the standard error decreases and tends to result in a lower p-value (Tomczak & Tomczak, 2014). Effect sizes that are large, but demonstrate non-significance may suggest further research in the area using greater power (Fritz et al., 2012). Equations for calculating Hedges g, used in the independent t-tests analysis, and point biserial r, used in the Mann-Whitney U analysis are listed below.

Hedges *g* Effect Size Calculation (*g*)

$$\mathbf{g}=\frac{\overline{x}_{1-\overline{x}_2}}{\frac{\sqrt{(n_{1-1)}s_{1}{}^{2}+(n_{2-1)}s2_{2}}}{n1+n2-2}}$$

$x_{1,2}$ – means of the first and second sample

n_1, n_{2} – the number of observations in groups (group 1, group 2)

s_1, s_2 – standard deviation in groups (group 1, group 2)

Point Biserial Effect Size Equation (*r*)

$$r = \frac{Z}{\sqrt{n}}$$

Z – standardized value for the U-value
r – correlation coefficient where r assumes the value ranging from –1.00 to 1.00
n – sample size

Effect sizes of .34, .24 and .10 represent large, medium and small, as suggested by McGrath and Meyer (2006) for point biserial *r* effect sizes. For Hedges *g*, effect sizes of .8, .5 and .2 represent large, medium and small effect sizes (Cohen, 1988).

CHAPTER 3 - RESULTS

Rate of hamstring injuries in the intervention period were not significantly different than the pre-intervention period, supporting the null hypothesis that the two groups were not different. A large effect size was found between the rate of hamstring injuries in the intervention period versus the non-intervention period. Average days lost per injury were not significantly different in the intervention period compared to the pre-intervention period, supporting the null hypothesis that the two groups were not different. A small negative effect size was reported for the average days lost per injury. No timeframes (pre-season, week 1-6 etc.) within the season were significantly different from the intervention years to the non-intervention years. Large effect sizes were seen at the week 1 through 6 timeframes.

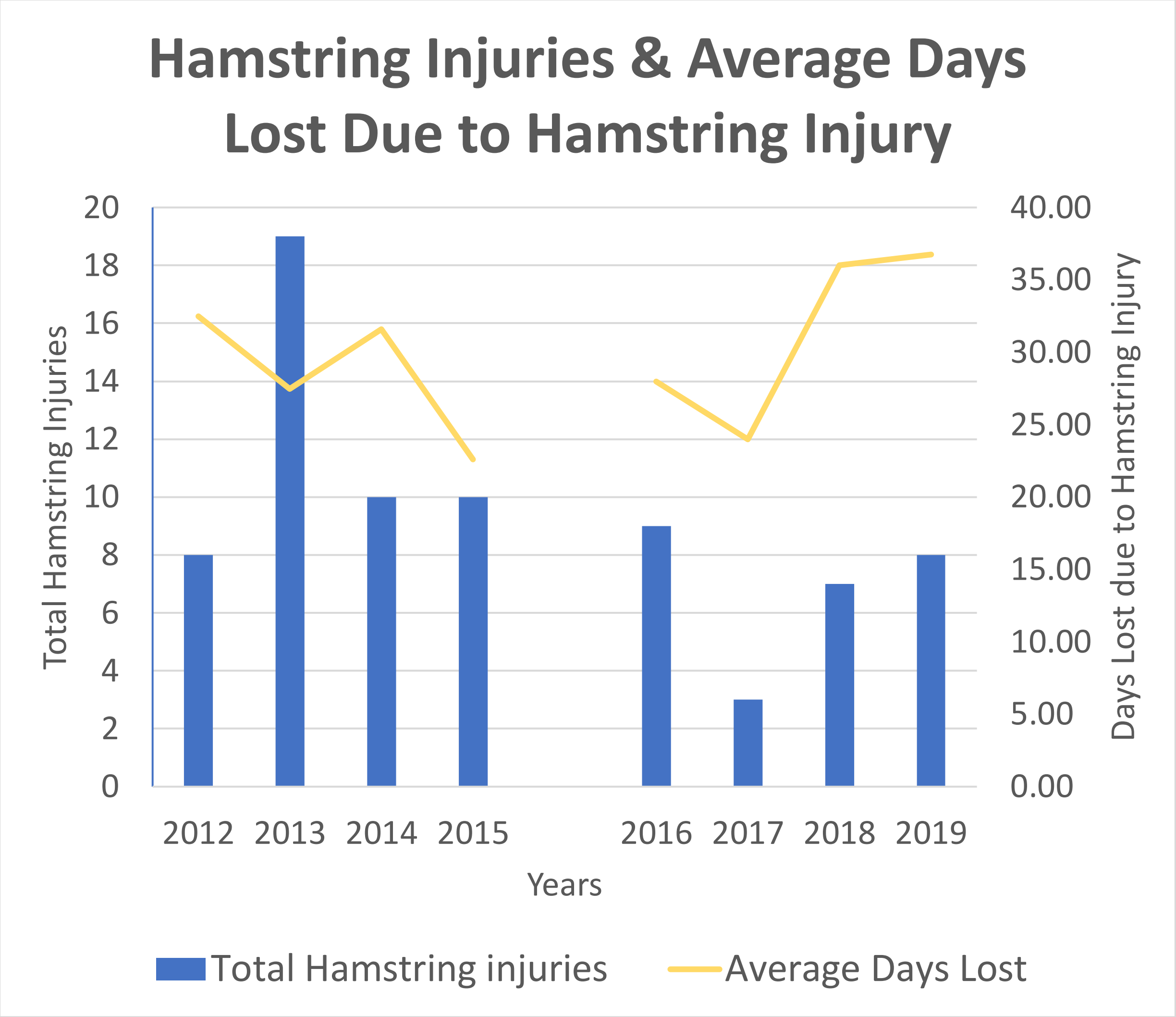
3.1 Independent t Tests Results

Independent t test results were deemed significant at $p \leq 0.05$ and are displayed in Table 1 below. The results of the first independent t-test analysis of hamstring injury rate compared between periods was $t(6) = 1.79$; $p = 0.12$; $g = 1.27$. The results of the second independent t-test analysis of average calendar days lost was $t(6) = -0.68$; $p = 0.51$; $g = -0.49$.

Table 1.

	2012-2015 No mNC		2016-2019 mNC				
	Mean	**SD**	**Mean**	**SD**	**df**	**p Value**	**Effect size (g)**
Rate of Hamstring Injuries	11.75	4.924	6.75	2.630	6	0.123	*1.27
Rate of Hamstring Injuries *including released players	12.25	5.188	9.5	3.109	6	0.39	0.651
Average Days Lost per Injury	28.54	4.526	31.18	6.216	6	0.517	-0.49
	Total MGL		**Total MGL**				
Man Games Lost Due to Injury	119		82				

Note: mNC – modified Nordic Curl; MGL - Man Games Lost; *Released players refer to players who were released from the team immediately after sustaining a hamstring injury and thus were not included in the calculation of average days lost due to hamstring injury; magnitude of effect sizes: trivial=<0.25; small=0.25-0.50; medium=0.50-0.8; large=>0.8; *=large effect size



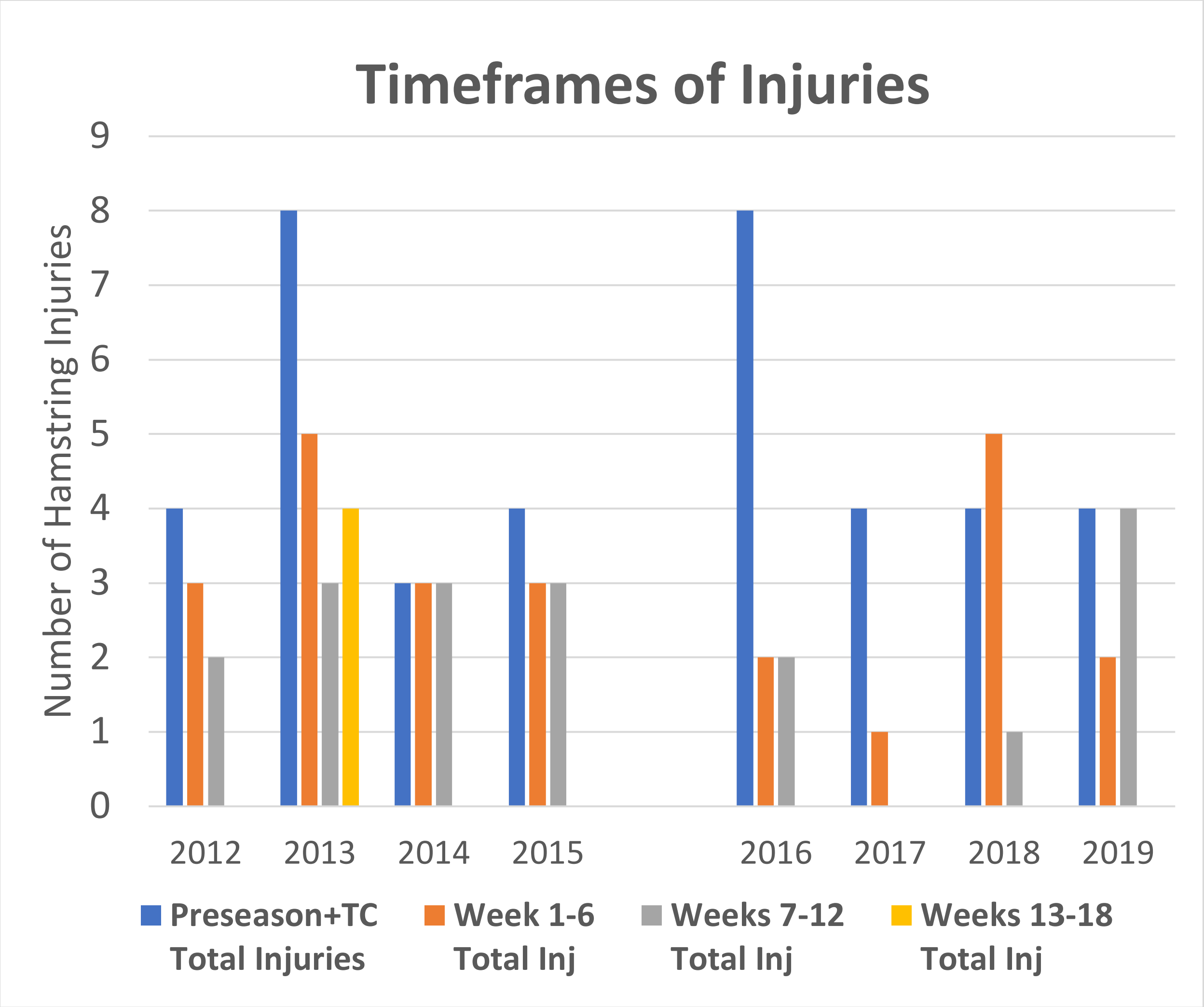
3.2 Mann Whitney U Test Results

Results of the Mann Whitney U test were deemed significant at $p \leq 0.05$ and are displayed in Table 2 below. The Mann Whitney U tests of comparisons of similar timeframes within the competitive season between the intervention period and the non-intervention period were all non-significant, (PS- U=6.5; p=0.685; r = -0.1; WK1-6- U=3.5; p=0.2; = r =0.41; WK7-12- U=4.5; p=0.34; r =0.31; WK13-18- U=6; p=0.68; r =0.15). Large effect sizes were seen at the week 1 through 6 timeframes (r =0.41).

Table 2.

	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	effect size r
Preseason	16.5	19.5	6.5	-0.2886	0.685	-0.102
Week 1-6	22.5	13.5	3.5	1.1547	0.2	*0.408
Week 7-12	21.5	14.5	4.5	0.866	0.34	0.306
Week 13-18	20	16	6	0.433	0.68	0.153

Note: mNC – modified Nordic Curl; magnitude of effect sizes: trivial=<0.1; small=0.1-0.23; moderate=0.24-0.33; large=>0.34; *=large effect size



CHAPTER 4 – DISCUSSION

This retrospective secondary analysis evaluated the effectiveness of a modified Nordic curl intervention on the rate, severity, and temporal comparison in one professional Canadian Football team. The primary results of the present study show that hamstring injury rates were not significantly different in the intervention period compared to the non-intervention period but did show a large effect size. Average days lost per injury were also not significantly different in the intervention period versus the non-intervention period but showed a small negative effect size. Based on statistical significance, these findings suggest that the first hypothesis of lower rate of hamstring injuries in the intervention period, and the second hypothesis of a reduction in the average time lost per injury in the intervention period, are not supported. The third hypothesis of a reduction in rate of hamstring injuries during the last third of the season in the intervention period was also not statistically different from the non-intervention period, with a large effect size reported in the week 1 through 6 timeframe during the intervention period.

4.1 Hamstring Injury Rate Between Periods

The results of the first independent t-test analysis revealed no significant difference between the intervention period and the non-intervention period but displayed a large effect size. This result could be attributed to the relatively low number of hamstring injuries in both periods, which were further reduced due to the elimination of 13 injuries that could not be included due to the player sustaining the injury being released shortly after sustaining the injury (<1 days after injury). While not statistically different, the four-year average of hamstring injuries decreased by 43% in the intervention period and showed a large effect size change. In real world application, a 43% decrease in hamstring injuries is a large change to a team's injury rate, representing 37 fewer man-games lost to injury compared to the non-intervention period. Man-games lost due to injury are an aggregate number of all the players not able to participate in games due to injury. For example, if 3 players all miss 6 games each, that team would report 18 man-games lost due to injury (3 players x 6 games = 18). When examining injury data, the number of man-games lost due to injury resulting from a specific injury may provide a quick and tangible indication of how one type of injury affects a team's injury rate. Man-games lost becomes difficult to apply to scientific studies due to the varying lengths of time between games in the CFL. Similar results were shown in regards to hamstring injury rate in a five year study of one professional soccer team implementing a conventional Nordic protocol, displaying a 55% decrease in hamstring injury rate from a non-intervention season, to the first season of the Nordic curl intervention (Chebbi et al., 2020). While the current study did not include injury incidence rate per hour of training exposure, a similar study involving professional soccer athletes performing a conventional Nordic exercise intervention over the course of 2 seasons showed a 65% decrease in hamstring injury incidence rate, when compared to 2 prior seasons of no intervention (Arnason, Andersen, Holme, Engebretsen, & Bahr, 2008). Injury incidence rate (±standard error) was calculated as the number of hamstring strains per 1000 hours of player exposure (match, practice, or total time). The large effect size demonstrated in this study suggests a meaningful change occurred, albeit with a small sample size (n=8). As previously mentioned, when large effect sizes are found with non-significant results, future studies should seek to reproduce the effects with a greater powered study (Fritz et al., 2012). The large effect observed provides a non-trivial amount of support for the use of the mNC in decreasing rate of hamstring injuries and warrants further research (Sullivan & Feinn, 2012).

4.2 Average Time Lost Per Injury Between Periods

The results of the second independent t-test analysis revealed no significant differences but displayed a small negative effect size, indicating the average calendar days lost due to injury were greater in the intervention period versus the non-intervention period (13% more time lost). These results align with that found by Petersen et al. (2011) investigating the effect of a Nordic curl intervention, which also showed a 13% increase in average time lost per hamstring injury, with an accompanying 71% decrease in reported hamstring injuries in a one year period of 2 large groups (intervention n=461 vs control n=481). In another large scale study of conventional Nordic exercise intervention, the results showed no difference in severity of hamstring injury in the two year intervention group, compared to the two year non-intervention group, in elite level soccer teams from Norway and Iceland (Arnason et al., 2008). The authors did not offer a potential explanation as to why the injury rate would decrease with an accompanying increase/no change in time lost (severity). One possible explanation is that the Nordic curl exercise can potentially limit the occurrence of less severe hamstring strains (1-17 days lost due to injury), but cannot affect more severe hamstring strains, of which some may include contact type injury. Indeed, in this study, a 59% reduction in less severe hamstring injuries (1-17 days) were seen in the intervention period, providing some evidence for the hypothesis that the mNC may chiefly effects less severe hamstring injuries, compared to more severe injuries. An alternative hypothesis might explore whether the mNC could increase the severity of hamstring injury due to the fatigue accumulated over the course of a season. This seems unlikely given the support the conventional Nordic curl has gathered throughout sport, but if a NC program was implemented with too rapid increases in volume of repetitions, a plausible overload in workload could be seen.

4.3 Total Hamstring Injury Rate Between Temporal Aspects of Season

The results of the Mann Whitney U tests revealed no significant differences between four different time periods throughout the competitive seasons and showed small to large effect sizes. It has been shown that pre-season tends to display the highest number of hamstring injuries, as indicated by Elliott et al (2011) 10-year epidemiology study of the National Football League's (NFL) preseason period which examined hamstring strains retroactively and found over half (51.3%) occurred in the 7-week preseason period. The temporal aspect of injuries was also investigated in a recent study of the influence of time of season on injury rates in the CFL over 8 seasons, and also showed a reduction in injury rate as the season progressed (~1% reduction in rate per week) (Robbins et al., 2020). This was also shown in the current study, as 45% of the injuries occurred in the 4-week preseason period. Preseason injuries tend to be the most difficult to change the incidence of, as player's level of physical preparedness will vary greatly among a 100-plus roster of athletes, and as such, it is a delicate balance between attempting to reduce physical stress on a player and ensuring they are adequately prepared to play competitive football. As the season progresses, interventions (such as the one is this study), attempt to curb these injuries. While the results of the Mann Whitney U test did not find significant differences in the 4 different time frames, there was a 53% decrease in hamstring injuries in the last two thirds of the season in the intervention period, compared to the non-intervention period. Again, from a clinically relevant standpoint, this is a large reduction in rate of hamstring injuries for one team. A potential explanation as to why no difference was found could be attributed to the low number of hamstring injuries sustained within each timeframe, in both the mNC period and the non-mNC period. Although this study did not include any data that would indicate if a player reinjured their hamstring at a later point in the same season, the occurrence of reinjury within the same season has been shown to be low in Nordic interventions used with professional sports teams (Arnason et al., 2008; Chebbi et al., 2020; Petersen et al., 2011).

Regarding the varying degree of effect sizes demonstrated, the two extreme opposites were found one after another, in the small negative effect observed during the pre-season timeframe, and weeks 1 through 6 timeframes displaying a large positive effect. As with most (if not all) injury prevention studies, no single variable will contribute solely to the reduction of injuries, and, as such, it becomes difficult to speculate as to why a small negative effect was detected, followed by a large positive effect (Goldman & Jones, 2007). One possible explanation could point to the evolution of training camp structure and workload throughout the 8-year timespan of the study. An increased demand in workload in training camp and preseason could potentially account for an increase in pre-season hamstring injuries in the intervention period, which would then act as a buffer to injuries in the first 6 weeks of the season due to a higher level of chronic fitness. This hypothesis would account for the higher recorded hamstring injuries in the intervention period during pre-season, followed by less recorded hamstring injuries in the intervention period compared to the non-intervention period during the timeframe of week 1 through 6. Another possible explanation for the disparate effects could be attributed to a survivorship bias. The increase in hamstring injuries in the intervention period (during preseason) could result from poor physical conditioning among the players entering training camp and subsequently injuring their hamstrings. This could potentially be followed by the majority of these players being released prior to the start of the season, thereby decreasing the bottom outliers of physical fitness, and keeping the players that were less likely to injure their hamstrings.

4.4 Methodological Considerations

One of the main limitations in this study is the weakness of the internal validity of the results. Foundations of Clinical Research (Portney, L. G., & Watkins, 2009, p.869) defines internal validity as: “the degree to which the relationship between the independent and dependent variables is free from the effects of extraneous variables”. Many confounding variables may be present at any one time in a professional sport environment, as often these athletes will have access to training routines and procedures, which all contribute in some way to maintaining an athlete’s health and performance. In these environments, the goal of the health care providers working with the team are results driven, and as such many treatment and training methods will be applied simultaneously with the goal of increasing performance and decreasing injuries through the accumulation of many smaller interventions. Variables such as the performance of the team and length of the seasons may have played a role in the outcomes of this study but were not able to be accounted for. The team's final standing during each year of the study were included below (Table 3). The league added one additional team in 2014 and games remained constant at 18 per season. An additional bye-week was also added to the start of the 2014 season, which extended the season duration from 19 weeks in length (1 bye-week), to 20 weeks in length (2 bye-weeks). Again in 2018, an additional bye-week was added to lengthen the season to 21 weeks (3 bye-weeks). This information may be thought of as a confounding variable that may indirectly affect the team's overall injury rate. While no studies may be able to conclusively indicate that teams that perform poorly in the standings tend to also display high levels of injury, this relationship may be seen in this study. In the non-intervention period, the highest the team finished was seventh out of eight teams. In the intervention period, the team finished in third on average throughout the four-year period. The team also finished with the lowest man-games lost due to injury in the league in all four years of the intervention. Man-games lost are a total number of games not played due to injury from all players missing that game. For example, if two players each miss 6 games due to injury during a season, that team would have 12 man-games lost due to injury (6 games x 2 players).

Table 3.

	Record (wins-losses)	League Ranking
2019	11-7	4th (9 teams)
2018	10-8	4th (9 teams)
2017	12-6	2nd (9 teams)
2016	11-7	3rd (9 teams)
2015	5-13	8th (9 teams)
2014	7-11	8th (9 teams)
2013	3-15	8th (8 teams)
2012	6-12	7th (8 teams)

Other variables that may have influenced the results include players being a part of both periods of the current study, coaching philosophies and their effect on training load/demands, new training methodology/equipment, playing surface changes, and compliance of athletes to the protocol. Lastly, this study could not account for variables such as previous history of hamstring strain, age of athletes and exposure hours to training/games, but future research in this area should seek to include these variables, as they may be available to the researcher. This study benefitted from having the same head Athletic Therapist to diagnose all hamstring strains throughout the 8-year period, which is a common limitation in hamstring injury studies, due to varying classifications of hamstring strains and different return to play specifications and milestones (Petersen et al., 2011). This study shares common limitations with other large scale Nordic intervention studies that occur over the course of multiple seasons, with player compliance to the protocols, blinding of participants, and team performance being the most commonly listed limitations (Arnason et al., 2008; Chebbi et al., 2020; Goode et al., 2015; Petersen et al., 2011). In this study, the non-intervention period consisted of poor team performances in both record/league standings and overall injury rate as measured through man games lost, whereas the intervention period showed upper-level team records/league rankings and the least amount of man games lost through each year of the intervention period. This result was also shown in one study of a conventional Nordic intervention, implemented over the course of 3 competitive seasons and 2 control seasons, of which 2 of the 3 intervention seasons resulted in an upper level final league ranking (Chebbi et al., 2020). In retrospective analysis, it is difficult to discern causation, and when using professional sports teams, it is illogical to infer causation due to many confounding variables, as listed prior. Team results may influence hamstring injury outcomes, or hamstring injury rates may influence team results, but it is impossible to discern which is the catalyst in the professional sport setting.

4.5 Generalizability of Results

The results of this study are similar to that of other studies which have used a Nordic curl intervention in elite sport settings, over the course of multiple seasons (Arnason et al., 2008; Chebbi et al., 2020). This study showed a decrease in rate of hamstring injuries in the intervention period, representing a 43% decrease in hamstring strains, and 37 fewer man games lost due to hamstring injury (players sustaining hamstring injury x number of games missed due to hamstring injury). A large effect size was shown in the reduction of rate of hamstring injuries, with a concomitant small effect size increase in average days lost in the intervention period. These results represent a theoretical trade-off between less injuries and more time missed on average per hamstring injury. This result could potentially be explained by changes in therapeutic care of injured athletes. It is generally thought that more time spent rehabilitating an injury results in less risk of re-injury and better long-term outcomes (Opar et al., 2012). This was shown in a longitudinal cohort study of 50 participants receiving eccentric-based rehabilitation after sustaining a hamstring injury (Tyler et al., 2017). Of the 50 participants, 8 were non-compliant to the three-phase rehabilitation protocol, and of those 8 participants, 4 re-injured their hamstrings. The rest of the 42 participants completed the protocol that lasted 11 ± 10 weeks, and did not sustain a reinjury at an average of 24 ± 12 months after return to sport (Tyler et al., 2017).

The low barrier to implementation in a CFL team, paired with the positive results should appeal to an Athletic Therapist or strength and conditioning professional working in the CFL or the NFL, to produce similar or better results. As mentioned previously, professional sports teams usually have access to training methods/equipment/staff that amateur level athletes do not, and as such, a protocol such as the one used in this study may provide a tool to the health and performance of elite football players. It is this authors opinion that these results may be generalized to other CFL teams and athletes, and to a lesser extent, NFL teams and athletes (due to differences in field size, number of downs, average body sizes and games played). While no significant results were displayed in this study, meaningful effects were shown, which provide some evidence to support the use of the mNC in the professional football setting.

CHAPTER 5 - CONCLUSION

In conclusion, the primary findings of this investigation are that there is no significant effect on hamstring injury rates, severity, or timeframe differences as a result of a four-year modified Nordic Curl intervention. This result could be attributed to the relatively low number of hamstring injuries in both periods, making any differences in the two time periods difficult to detect. Severity of injury was similar in both time periods, with a slight increase in average days lost occurring in the intervention period. One possible explanation for this is that the Nordic curl exercise can potentially limit the occurrence of less severe hamstring strains (1-17 days lost due to injury), but cannot affect more severe hamstring strains, of which some may include contact type injury. The final findings showed no difference at any timeframe in the season when investigating total injuries at four different timeframes. A potential explanation as to why no difference was found could be attributed to the low number of hamstring injuries sustained within each timeframe, in both the mNC period and the non-mNC period. These findings may influence a strength coach's or athletic therapist's decision to implement a modified Nordic curl program with their respective team or group of athletes.

5.1 Future Directions for Research

Currently, there exists a limited amount of research surrounding the Canadian Football League that examines player injury outcomes, when compared to the literature available from National Football League sources (Robbins et al., 2020). Future research should involve athletes that play Canadian rules football, with the major differences between the American version being: 3 vs 4 downs, more players on the field (12 vs 11), and larger fields (110 by 65 vs 100 by 53.3 yards). Canadian strength and conditioning professionals will often use available football literature to guide their training philosophy, and therefore the athletes they are training are being trained for American rules football, instead of the Canadian version due to the lack of research surrounding the Canadian rules version. Research using Canadian rules football will allow strength and conditioning professionals and Athletic Therapists working with Canadian teams to provide more specific interventions to the athlete's sport.

Future research should seek to ensure maximum compliance to a daily protocol, involving a slowly increasing number of Nordic repetitions completed, up to a maximum daily number. The "micro-dosing" approach to Nordic reps involves smaller numbers of repetitions completed daily when compared to conventional protocols but are carried out more frequently.

Future research should also investigate a more intensive version of the conventional NC, in which the athlete is asked to concentrically contract back to the starting position of fully upright posture with every repetition, as opposed to the conventional method of only completing the eccentric portion. The theoretically increased intensity of this modified Nordic version could reduce the number of repetitions needed to elicit a change in hamstring injury risk. Previous research has shown the highest EMG activity is seen when the knee is extended to the greatest position prior to falling, and in theory, large amounts of torque would be required to concentrically contract back from a position of near end range knee extension (Delahunt et al., 2016; Iga et al., 2012). Future research could also account for athlete exposure time to training, practice and games to make yearly comparisons more accurate across multiple seasons of play. This would involve recording the time spent in training, practice and games and calculating the rate of injury in each of these areas and comparing specific stress from one season to another.

5.2 Funding

No funding was provided for this retrospective study.

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