The Effect of a Skate Treadmill Training Intervention on Stride Mechanics

Dylan Lamers, BKin, MSc Candidate

Submitted in partial fulfillment of the requirements for the degree of
Master of Science in Applied Health Sciences
(Kinesiology)

Under the supervision of Dr. Kelly Lockwood, PhD

Faculty of Applied Health Science, Brock University
St. Catharines, Ontario

Abstract

The evolution of sport performance has been supported by the development and integration of advanced training devices and practices aimed at eliciting both physiological and mechanical adaptations. The primary purpose of the study was to investigate the effect of a 12-session skate treadmill training intervention on stride mechanics in youth ice hockey players. The secondary purpose was to investigate the effect of removing the training stimulus on retention of stride mechanics adaptations as a result of training. Stride mechanics were defined by the variables: stride length (SL·mm), stride frequency (SF·Hz), and select kinematic measures of the trunk, hip, and knee angles (°). Twenty-three ice hockey players (9.7 ± 0.5 y) completed an A-B-A, within-subject, quasi-experimental training intervention. Twelve treadmill sessions were scheduled over 9 weeks. Block A was defined by sessions 1-6 and 7-12, and included pre^1-post^1 and pre^2-post^2 assessments. Block B was defined by the time between sessions 6 and 7, whereby the training intervention was removed. The duration of Block B was consistent with the time to complete Block A (sessions 1-6 and 7-12), respectfully. Pre-post assessments included, anthropometric measures of [standing and sitting height (cm), weight (kg)], vertical jump height (cm), and stride mechanics. Stride mechanics, namely SL (mm), SF (Hz), and joint angles (°), were obtained from video analysis conducted at a constant treadmill speed (10 mph) and incline (5 °). While directional changes of improvement, namely increasing SL, decreasing SF, and increased knee flexion at weight acceptance were observed pre-post training sessions 1-6, 7-12 and overall, 1-12, the changes were not significant. Significant differences in hip and knee angles following toe-off pre-post training sessions 1-6 and sessions 1-12 were revealed ($p < .05$). No significant differences in stride mechanics pre-post training sessions 6-7 were revealed, indicating that the improvements seen through sessions 1-6 were retained. Pearson product moment correlations revealed significant correlations between SL and trunk and hip and knee angle following toe-off at A_{post1}, and between SL (mm) and knee angle at weight acceptance (°) at A_{post2} ($p < .05$).

Acknowledgements

This study and Master's degree has been a journey full of memories and experiences that I will take with me throughout the remainder of my life. I would not have been able to finish this degree without the love, support and guidance of the many people involved. I would like to thank my supervisor Dr. Kelly Lockwood for the immeasurable number of meetings, edits, discussions and guidance. You have influenced me not only as a student but as a person and I cannot express the gratitude that I have for the amount of time and effort you put in to help me reach this milestone in my life. To my committee members Dr. Michael Holmes and Dr. Michael Plyley for your expertise, and feedback, as well as always taking time chat or take video calls. Without the guidance and support of each of you I would not have been able to complete this my Master's degree.

To my Mom and Dad, brothers and sister, Grandmother and Grandfather thank you for everything you have done for me and helped me with. Thank you for always supporting me and listening to me all these years even if you didn't want to sometimes and providing me with the opportunity to be the person I am today.

To my fellow graduate students and good friends Vince Iantomasi, Colin Dunne, Cam Ormrod and Ryan Bench for all of your help with training and data processing. Thank you to all of you for all of the laughs in the lab, in class and everywhere in between, I consider myself privileged to have met each one of you. Vince, thank you for all the chats and being there every step of the way as I navigated graduate school.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

The evolution of sport performance has been supported by the development and integration of advanced training devices and methodologies aimed at eliciting both physiological and mechanical adaptations. Simulated training devices and refined training protocols have been investigated to augment traditional dryland and/or sport specific movement patterns and potentially enhance sport performance. For example, rowing machines, cycle ergometers, and running treadmills are all simulated devices traditionally used in training. Skate treadmills, first commercially produced in 1995, were designed to teach and train skating technique in a controlled training environment simulating on ice skating conditions (Lepine & Frappier, 1995). Treadmill speed and incline can be adjusted to elicit a biomechanical response and to provide progressive overload in a controlled training environment that allows the trainer to easily provide feedback on technique during training (Schweigert & Frappier, 2002; Swanson, n.d.). The effects of combining the use of a skate treadmill (infrastructure) with sport-specific training (expertise) have been previously investigated in ice hockey players, resulting in positive physiological (Harris, 2010), biomechanical (Tidman, 2015), and conceptual outcomes (Lockwood & Jackson, 2010). However, a dose-response relationship for mechanical adaptation has not been explored.

Athlete development in Canadian sport has been guided by the Long Term Athlete Development (LTAD) model and was adopted by Hockey Canada (2013). The LTAD model is focused on healthy development with reference to growth, maturation, and trainability that serves as a guide to the enhancement of optimal training programs for the developing athlete (Balyi, Hamilton, & Robertson, 2005). The LTAD model is categorized by stages, beginning with Active Start, which emphasizes play and development of balance and movement techniques, FUNdamentals, which emphasizes play and serves as an introductory stage to the learning of a variety of fundamental skills used in a variety of sports. The LTAD model suggests that basic sport skills, or what is referred to as mechanical or technical training, can be effectively introduced during the Learn to Train stage of development and further developed in the Train to Train stage as both are defined as a sensitive period of skill acquisition (Higgs, Balyi, Way, Cardinal, Norris, & Bluechardt, 2016; Higgs, Balyi, Way, Cardinal, Norris, & Bluechardt, 2017; Higgs et al., 2019).

In the sport of ice hockey, a sport-specific skill, like forward skating, is fundamental and an essential building block to the development of most other on-ice skating skills. The biomechanics of a forward skating stride has been well documented (Marino, 1974; McPherson et al., 2004; Pearsall, Turcotte, Murphy, 2000; Pearsall et al., 2001; Renaud et al., 2017; Shell et al., 2017; Upjohn et al., 2008); it is biphasic, meaning it is comprised of a support phase, when the skate blade contacts the skating surface, progresses through glide and push-off and a swing phase, the recovery of the ipsilateral limb to the next contact of the foot with the skating surface (Pearsall, Turcotte, Murphy, 2000), and cyclical, meaning that the process that occurs with one limb will also occur in the other. The mechanics of forward skating is learned and acquired through physical practice. Physical practice requiring multiple repetitions has been referred to as crucial to the learning and attainment of most motor skills (Trempe et al., 2011; Trempe & Proteau, 2012).

Research investigating the effectiveness of simulated training devices (infrastructure) and protocols (expertise) on stride mechanics are limited and provide little information on the dose-response relationship for mechanical adaptation. An isolated study investigating habituation to a skate treadmill in youth was conducted by Lockwood & Frost (2007) and was the foundation of the current study. Results suggested that familiarization to a simulated device, such as a skate treadmill, occurs relatively quickly (8 minutes), followed by training adaptations. Training adaptations consisted of significant increases in stride length at a submaximal speed and significant decreases in stride rate, heart rate, and ratings of perceived exertion (Lockwood & Frost, 2007). A skate treadmill and dryland training study conducted by Harris (unpublished Masters thesis, 2010) examined the effect of an eight-session skate treadmill training intervention on sport-specific measures of skating, stick handling and puck control movements in competitive youth ice hockey players. The results provided support for physiological and mechanical adaptations in skating in youth ice hockey players, however the study did not explore retention of adaptations once the training stimulus was removed.

The primary purpose of the study was to investigate the effect of a twelve-session skate treadmill training intervention on stride mechanics in competitive, youth, ice hockey players (9.7 ± 0.5 y). The secondary purpose of the study was to investigate the effect of removing the training stimulus on retention of stride mechanics adaptations as a result of training. Stride mechanics was defined by the following variables: stride length (SL, in mm), stride frequency (SF, in Hz), and select kinematic measures of the trunk, hip, and knee angles (°). The knowledge gained from the study has the potential to inform the scientific and athletic community on the dose-response relationships between skate treadmill training and adaptations in stride mechanics, and insight into the expected ‘retention’ of the mechanical adaptations.

Chapter 2: Review of Literature

The game of ice hockey is a high intensity and complex sport that requires athletes to continually develop and refine various aspects of their game to maintain the highest level of performance. Research investigating the effectiveness of simulated training devices (infrastructure) and protocols (expertise) on stride mechanics are limited and provide little information on the dose-response relationship for mechanical adaptation. Research has been reported on how to effectively develop sport-specific skills and how to train young, developing athletes. The current study will explore the dose-response relationship by examining the effect of twelve sessions of skate treadmill training on stride mechanics in youth ice hockey players.

2.1 Simulated Devices and Training

Skate treadmills were first commercially produced in 1995 and have been designed to teach and train skating technique while in a controlled training environment that simulates on-ice skating conditions and allows the trainer to easily provide feedback on technique during training (Lepine & Frappier, 1995). Treadmill speed and incline can be adjusted to provide a progressive overload to elicit a biomechanical response (Schweigert & Frappier, 2002: Swanson, n.d.). Treadmills allow athletes to run/skate at a steady speed and can be used to force athletes to run or skate a little faster in order to match that speed, thus aiding in improving speed and technique. The visual, audio, and kinesthetic feedback that the athletes get from the treadmill training environment can all help improve and reinforce proper movement and technique/mechanics with the aid of a coach or trainer (Schweigert & Frappier, 2002; Swanson, n.d.). From a hockey perspective, simulated training devices offer a feasible alternative to scarce and expensive ice time (Lockwood and Jackson, 2010).

The skate treadmill as a training modality, allows coaches and trainers to detect errors and provide corrective feedback or criticism to aid in the attainment of proper or improved skating technique (Dreger, 1997). Dreger (1997) suggests that the skate treadmill can aid in the development of good skating technique which can to lead to greater skating speed and efficiency. Skate treadmill facilities are fitted with mirrors surrounding the treadmill so that the athlete can benefit from their own visual feedback. Nobes et al. (2003) compared the skating economy on ice (140m oval track) versus on a skate treadmill on fifteen male varsity hockey players (mean age = 21 y). Measurements included oxygen expenditure, heart rate, stride rate, and stride length at three different velocities (5.0 $m \cdot s^{-1}$, 5.6 $m \cdot s^{-1}$, and 6.1 $m \cdot s^{-1}$). The subjects' oxygen consumption ($p < 0.01$), heart rate ($p < 0.01$), stride rate ($p < 0.01$), and stride length were higher on the treadmill versus on-ice, and the greatest differences were observed at slower velocities. Oxygen consumption on-ice was significantly lower than on the treadmill, mean VO_2max was similar, heart rate was significantly higher on the treadmill than on-ice, and stride rate was significantly higher on the treadmill than on-ice.

Stidwill et al. (2010) assessed the skating kinetics and kinematics of eleven, varsity level, male, hockey players both on ice (oval track) and on a synthetic ice surface. Subjects were required to perform 5 maximum effort skating starts on both surfaces. The co-efficient of friction for the synthetic ice surface was reported as $\mu = 0.27$, while the co-efficient of friction for the regular ice was $\mu = 0.003$ to 0.007 (Stidwill et al., 2010). Results revealed that the kinetic and kinematic measures were virtually the same for both skating surfaces ($p > 0.06$). For kinematics, results revealed that mean maximum knee extension amplitude was significantly different between conditions, with increased extension occurring during skating on a synthetic ice surface than on-ice (11.0° vs. 15.2°; $p < 0.05$), but knee angle at maximum flexion was similar ($p \geq 0.11$,

$p \geq 0.14$). Stidwill et al. (2010) reported that synthetic ice surfaces which are similar to skate treadmills offer comparable mechanics to on-ice forward skating. The data indicate that skate treadmills can be used as an effective modality to train stride mechanics as long as the training is conducted with an appropriate coach or trainer experienced in the use of skate treadmill training. and the research supports the notion that synthetic ice-skating surfaces, such as skate treadmills, can offer similar skating mechanics to those seen on-ice.

The effects of combining the use of a skate treadmill (infrastructure) with sport-specific training (expertise) have been investigated in ice hockey. Harris (unpublished Masters thesis, 2010) examined the effect of an eight-session Degree of Separation skate treadmill and dryland agility training intervention on sport-specific measures of skating, stick handling and puck control movements in competitive ice hockey players. Sixteen male, Major Bantam and Minor Midget hockey players (14 y) and ten aged matched controls were recruited for the study. All players played the position of forward or defense and had previous skate treadmill training exposure. Both the experimental and control group completed pre and post Cunningham-Faulkner skate treadmill test, which was defined as the total amount of time (s) that players could skate on the treadmill at a constant speed (16 km/h) and incline (16°) without assistance, and Degrees of Separation Skate Treadmill tests, to assess the ability to sequence the lower body (skating) and upper body (stick and puck handling) paired with a cognitive measure. The experimental group completed two 90-minute training sessions per week, over four weeks, including 45 minutes of skate treadmill training and 45 minutes of Speed, Agility, and Quickness training, while the control group received no training. Results revealed significant improvements in pre-post measures of the modified Cunningham-Faulkner test and the Degrees of Separation tests in the experimental group as a result of the training intervention (Harris, 2010).

Specifically, the experimental group revealed a significant increase in their Cunningham-Faulkner skate treadmill test in terms of total time skating, with no significant increase in stride rate compared to the control group. These results suggest that the experimental group showed positive physiological and mechanical outcomes by extending the duration of the Cunningham-Faulkner test with less strides compared to the control group.

Lockwood and Jackson (2010) developed a model of age and ability appropriate sport-specific training for ice hockey players. They examined the impact of system level and athlete level factors that influence stakeholders' decisions to access and/or integrate infrastructure into athlete development and how innovative infrastructure can provide effective support of LTAD at all stages of development. The study utilized a Hockey Intervention Program that paired a skate treadmill (infrastructure) and expertise (sport-specific support) in the form of highly qualified trainers. At the system level, data were collected from open ended surveys and interviews of 160 stakeholders about the role of infrastructure supporting athlete development. At the athlete level, 140 hockey players were sampled, 20 athletes for each of the seven stages of LTAD. Physiological, biomechanical, and on-ice performance measures were assessed pre and post a 12-week Hockey Intervention Program training intervention per year for two years. Biomechanical measures were used to assess changes in mechanical skill acquisition and refinement of technique, physiological measures were used to assess changes in fitness level, and sport-specific performance measures assessed the transference of dry-land training to on-ice performance. Results of the study from the system level highlighted support for the program falling into three themes including the reasons for accessing sport specific infrastructure, the timing of 'first-access' of sport specific infrastructure, and the quality of facility time and expertise associated with sport specific infrastructure exposure. Results from the athlete level, revealed significant pre-post differences in three themes across all stages of the LTAD model: (i) mechanical literacy; (ii) confidence; and (iii) physical literacy increased, as a result of the Hockey Intervention Program. The study reported that alternative infrastructure (skate treadmill training) is an effective way to teach, learn and train basic sport skills; skate treadmill training is an effective alternative to add to scarce and expensive ice time; and the need for certification of trainers and coaches is key to positive outcomes.

Tidman (unpublished Masters thesis, 2015) examined the effects of technical training and hockey skate design on the biomechanics of a forward skating stride on a skate treadmill. Fourteen, male, (12-16 y old) participants with no recent skate treadmill experience completed 10 skate treadmill training sessions over 2-3 months, each session was 45 minutes in duration and focused on increasing stride width. A six camera-Vicon Motion Analysis system was used to capture 3D biomechanical measures of stride width, stride rate, and angles of the torso, hip, knee, and ankle while skating on a skate treadmill. Results revealed after 5 sessions of skate treadmill training, a significantly increased knee flexion at foot strike ($p < 0.01$), increased ankle flexion at foot strike ($p < 0.05$), increased ankle ROM ($p < 0.05$), decreased stride rate at a constant treadmill speed ($p < 0.05$), and increased stride width ($p < 0.05$).

Lockwood & Frost (2007) evaluated seven Atom A ice-hockey players who completed six-weeks of skate treadmill training once per week, with a 1:3 work to rest ratio. The goal of the study was to determine how long the participants took to habituate to the skate treadmill, and to assess changes in physiological and kinematic variables over a 6-week training period on a skate treadmill. The results revealed that familiarization to a simulated device, such as a skate treadmill, occurs relatively quickly (8 minutes), followed by training adaptations. Training adaptations consisted of significant decreases in stride rate, heart rate, and ratings of perceived exertion, and significant increases were revealed in stride length at a constant speed. Overall, the results met the criteria of habituation in Atom A ice hockey players. Training adaptations in stride length and stride frequency were revealed following one week of training, and all remaining adaptions were present by week 4. The use of a skate treadmill for training can elicit biomechanical changes or adaptations in skating stride, if athletes are provided with training expertise.

2.2 Training Youth

The Canadian Society for Exercise Physiology (CSEP) released a report concerning the recommended amount of physical activity that children and adolescents should take part in daily. The Canadian 24-Hour Movement Guidelines for Children and Youth (2020) from CSEP, recommended that children and adolescents ages 5 to 17 should partake in 60 minutes or more of moderate-to-vigorous physical activity per day. Additionally, children and adolescents should partake in muscle strengthening, bone-strengthening, and vigorous intensity physical activities a minimum of three days per week.

The Long-Term Athlete development (LTAD) model suggests guidelines for teaching skills to young athletes. The LTAD model is based upon the general framework of healthy development with reference to growth, maturation and development, and trainability that serves as a guide to the advancement of optimal training, competition and recovery programs for the developing athlete (Balyi, Hamilton, & Robertson, 2005). The LTAD model is built upon the idea and importance of physical literacy. The LTAD model suggests that physical literacy is the foundation of excellence in sport and physical activity (Higgs et al., 2017). The development of physical literacy should be the primary focus before the adolescent growth spurt. Physically literate individuals should demonstrate fundamental movement skills and sports skills, i.e., move with poise, confidence, competence, and creativity in different physical environments (on the ground and on the ice), and develop the motivation, ability, and knowledge to understand, communicate, apply and analyze different forms of movement. The LTAD model supports that skating is a fundamental locomotor skill that underpins physical literacy (Higgs et al., 2017). The LTAD model describes the progression for developing skill in athletes through eight distinct stages – (a) Active Start (ages 0-6 boys & girls) which emphasizes play and development of balance movement techniques; (b) FUNdamentals (ages 6-9 boys, ages 6-8 girls), which emphasizes play and serves as an introductory stage to the learning of a variety of fundamental skills used in a variety of sports; (c) Learn to Train (ages 9-12 boys, 8-11 girls), (d) Train to Train (ages 12-16 males, ages 11-15 females), (e) Learning to Compete, (f) Training to Compete, and (g) Training to Win (Higgs et al., 2016). The LTAD model suggests that basic sport skills, or what is referred to as mechanical (technique) training, can be effectively introduced during the Learn to Train stage of development and further developed in the Train to Train stage as both are defined as a sensitive period of skill acquisition. Evidence has also been provided to support the idea of accelerated adaptation to training during several "windows of trainability", i.e., periods in the athlete's different stages of growth and maturation in which the body is ready to respond to training (Higgs et al., 2017). More specifically, there is a window of accelerated adaptation for developing skills in males between the ages of 9-12 y, and 8-11 y in females, i.e., before the onset of the growth spurt, as children are developmentally ready to acquire the general sports skills that are crucial to athletic development (Higgs et al., 2017).

The LTAD model was updated in 2019 to the Long Term Development (LTD) in Sport and Physical Activity (Higgs et al., 2019). The definition of physical literacy was updated as physical literacy is the motivation, confidence, physical competence, knowledge, and understanding to value and take responsibility for engagement in physical activities for life (Higgs et al., 2019). However, much of the core framework from the previous LTAD model remained the same, with some slight adjustments to the sensitive periods for the Learn to Train stage of development with less of a focus on chronological age. The Learn to Train stage, in which is considered a sensitive period for skill acquisition and fundamental skill building has been adjusted to encompass young individuals between approximately 9 years old and the onset of the growth spurt for boys and between approximately 8 years old and the onset of the growth spurt for girls (Higgs et al., 2019).

Hockey Canada (2013) adopted the guidelines of the LTAD model as a result of the Canadian Sport Policy 2012, with a specific focus on the long-term development of hockey players and the specific skills as they relate to the sport. Hockey Canada (2013) also highlights that there is a window of trainability for children between the ages of 9-12 where they can develop motor skills, such as forward skating, that will be integral to develop other skills that transfer to in-game play.

2.3 Developing Sport Specific Skills

In general, motor skills are primarily learned through physical practice or learning that occurs as a result of performing a skill through repetition. Physical practice is defined as performing physical work repeatedly in order to become proficient (Practice, 2019). Physical practice is the main stimulus for learning a motor skill, and through repetition gives the learner the chance to understand and fine tune the movement pattern through sensory consequences of the movement/skill being learned (Trempe, Sabourin, Rohbanfard, & Proteau, 2011; Trempe & Proteau, 2012). Trempe et al. (2011) investigated the effect of observational learning versus physical practice on task consolidation/learning in a movement timing task. The study, conducted on undergraduate students, consisted of three experiments in which observational learning was compared to physical practice. The results of the study determined that physical practice was necessary in order to learn a movement sequence pattern, and that observational learning alone was not enough to learn a movement sequence pattern (Trempe et al., 2011). Trempe and Proteau (2012) published a book on skill acquisition in sport, including research reports regarding physical practice and skill acquisition. Research highlighted that motor skill acquisition and expertise requires practice, and repeated physical practice can aid in the retention of motor skills. Sport-specific motor skills, like forward skating, are normally introduced, learned and perfected through multiple repetition-type practices.

The Coaching Association of Canada (CAC, 2020) provides coaches with information and reference material on how to develop sport skills in developmental athletes within their National Coaching Certification Program (NCCP). The CAC (2020) defines the development of skills into five stages including initiation, acquisition, consolidation, refine, and create variations. The first stage of skill development – initiation, begins with athletes getting their first contact with the skill, but during this stage athletes must be provided with a clear mental picture of what correct execution of the skill entails and gain a fundamental understanding of the positions and patterns of the skill. The second stage of acquisition deals with the early stage of learning. During this stage, the athletes become capable of coordinating key aspects of the movement and execution of those aspects in the correct order; however, the movement may lack precision, consistency and athletes need to think consciously about the pattern of movement. During the second stage, athletes have a clear mental image of the task, and must practice multiple times in order to acquire the skill and determine solutions about improving the skill using trial and error based on coach or trainer feedback. The remaining three stages of consolidation, refinement, and creativity concerns athletes becoming comfortable with the movement pattern, being able to execute that skill in a variety of situations under pressure. Here, the movement becomes smooth as the athletes become more proficient in the execution of that skill, develop their own personal style through practicing in various situations with little to no coach or trainer feedback.

2.4 Hockey Skills

The game of ice hockey is a skill-based sport that requires the technical skills of skating, shooting, stickhandling, checking, and passing. Skating can be split into the categories of forward and backward skating. In ice hockey, a sport-specific skill, like forward skating is fundamental and an essential building block to the development of most other on-ice skating skills. Forward skating performance relies on the combination of physical (strength/power) and mechanical (technique) abilities to achieve the most effective skating stride. Time motion analysis studies have investigated skating statistics (Jackson, Snydmiller, Game, Gervais, and Bell, 2016; Montgomery, Nobes, Pearsall, and Turcotte, 2004). Montgomery et al. (2004) conducted a task analysis to determine how much time was spent on various particular skills during the course of a hockey game, based on player position. The study determined that respectively, total forward skating activities (e.g., forward skating, sharp turns, changes in direction, starts, stops, and crossovers) comprised 258 forward skating activities for the position of Center, 227 forward skating activities for the position of Winger, and 270 forward skating activities for the position of Defense. Total backward skating activities (e.g., backwards skating, crossovers, changes in directions, sharps turns, starts and stops) were 43 backward skating activities (Center), 44 backward skating activities (Winger), and 146 backward skating activities (Defense) (Montgomery et al., 2004). Time motion analysis determined that in the positions of Center, Winger, and Defense, the amount of time spent in backwards skating was 4.8%, 5.7%, and 19.2 %, respectively; with the rest of the time being spent forward skating (Montgomery et al., 2004). Similarly, Jackson et al. (2016) conducted a time motion analysis to determine the rate and duration of movements that female ice hockey players perform during the course of an ice hockey game. The movements of 22 female university level ice hockey players were filmed and tracked during three regular season games. Results revealed that the female hockey players spent 36.3 % (± 6.2%) of the games forward gliding on ice, 31.2 % (± 6.2%) forward skating at a moderate intensity, 5.3 % (± 3.3%) forward skating at maximal intensity, and the remainder in backward glide, standing, struggling for the puck or for position, or backwards skating at moderate intensity (Jackson et al., 2016). This study supports the contention that the majority of ice hockey is spent forward skating, no matter if it is male or female ice hockey.

Renger (1994) conducted a study that utilized the qualitative analysis of NHL scouting reports to determine what scouts deemed as necessary skills or task requirements were essential for success in ice hockey. Results revealed that for both forwards and defensemen, the most important skill was skating (Renger, 1994). These time motion and qualitative analysis studies highlight the importance of the skill of forward skating for the positions of forward and defense and how the development and refinement of this skill is important to the success of a hockey player.

2.5 Biomechanics of Forward Skating

The forward skating stride is biphasic and cyclical, consisting of a support phase and a swing phase. The support phase can be further sub-divided into a single and double support phase, occupying 18% and 82% of the total support phase (Pearsall et al., 2000; Upjohn et al., 2008). The forward skating stride begins after the outward rotation of the thigh, and matches up with the initial extension of the knee and hip initiating the propulsion of the skater. As the contralateral skate touches down, the propulsive limb initiates push-off by utilizing the extension of the knee, hyperextension and abduction of the hip, along with plantar flexion of the ankle (Pearsall et al., 2000; Upjohn et al., 2008). The support phase is load bearing, and can be separated into the glide and the push. The glide is load bearing, and occurs as the foot comes into contact with the skating surface, pointing in the direction of travel. The glide turns into the push via the external rotation of the hip. The push progresses with the extension of the hip and the knee, and ends with the toe-off of the foot. The swing phase is the recovery of the ipsilateral limb. Following toe-off, the pushing foot leaves the skating surface and recoils underneath the hip, with the hip and knee flexing to bring the foot back into the glide position. This process is repeated with the contralateral limb, completing the forward skating's cyclic movement pattern. The efficiency of a forward skating stride can be estimated by that of an athletes' stride length and stride frequency. Stride length is displacement of the foot from the most anterior position of that foot during the glide to the most posterior location of the same foot, following the push. Stride frequency is the rate at which the foot moves through the glide, push-off, and recovery of each limb in a cyclical pattern.

Research investigating the biomechanics of a forward skating stride, commonly referred to as stride mechanics has primarily focused on an adult male cohort, skating on ice, with limited research on the young developing athletes (Marino, 1974; McPherson et al., 2004; Pearsall, Turcotte, Murphy, 2000; Pearsall et al., 2001; Renaud et al., 2017; Shell et al., 2017; Upjohn et al., 2008). Early research by Marino (1974) identified important aspects of the skating stride by observing skaters of different abilities at various speeds on ice. Results revealed that velocity increases were correlated positively with increases in stride frequency and decreases in double support time. Stride frequency was positively correlated with speed rather than stride length.

Above-average skaters produced higher stride rates, longer stride lengths, and longer glide phases than skaters of below-average ability at maximal velocity (Marino, 1974). Furthermore, above-average performers displayed less flexion of the lower leg, and consequently, vertical displacement of the foot was less during the recovery phase of the forward skating stride (Marino, 1974). Upjohn et al. (2008) conducted a study to describe lower limb kinematics in three dimensions during the forward skating stride in adult, male ice-hockey players, on a skate treadmill, and to contrast skating techniques between low and high calibre skaters. Subjects were required to skate at a self-selected maximum speed that they could maintain for one minute at a treadmill incline of 2 degrees. Data of lower limb kinematics was captured using a four-camera 3D motion capture system and processed using Matlab. Results revealed high-calibre participants, achieved faster skating velocities than low-calibre participants even though their stride rates were similar. High caliber participants demonstrated both significantly greater stride length and stride width than low-calibre participants. High-calibre athletes demonstrated greater hip flexion at weight acceptance ($p < 0.001$), greater knee extension and plantar flexion at propulsion ($p < 0.001$; $p < 0.02$), and greater knee and ankle–foot ranges of motion ($p < 0.01$; $p < 0.02$). High-calibre skaters presented greater limb excursion (lateral displacement of lower limb segments), and a larger range of motion for the pelvis, thigh, and foot ($p < 0.03$; $p < 0.01$; $p < 0.07$).

Pearsall et al. (2001) reported on the kinematics of the foot and ankle in forward skating, on ice, in three male varsity level hockey players using two twin axis electro-goniometers placed on the posterior ankle of the subjects. The subjects were instructed to perform a parallel start from their particular defensive zone face-off circle, then skate toward the corresponding offensive face-off circle, and ended the trial with a crossover stop (Pearsall et al., 2001). Angular measures were reported in relation to the subject's on-ice neutral standing position. Maximum angular range of motion values in the sagittal and frontal plane were measured. Only the right foot was measured due to the biphasic nature of a skating stride. Results revealed that the acceleration phase was during the first 5 steps, and that steps 6 to 10 comprised steady state skating. Results revealed that the skating cycle began with initiation of the single support phase, and that the skate was dorsiflexed 7.1° at initiation. As the single support phase ended and the double support phase began at approximately 31% of a finished stride, the right skate increased dorsiflexion, reaching a cycle peak of 11.8°. Following the end of the push-off, the blade of the right skate elevated off the ice to initiate a swing phase, and subjects actively plantarflexed from 11.8 ° of dorsiflexion to 1.9 ° of dorsiflexion. The right foot was dorsiflexed in relation to the neutral position throughout the cycle. This study was able to provide quantitative data to aid in describing the kinematics of the forward skating stride. Shell et al. (2017) reported the kinematic differences between the skating stride of 9 elite male and 10 elite female skaters during a forward skating start on ice. An 18-camera motion capture system was placed on the ice skating surface to capture full-body kinematics during the first six steps of a maximum acceleration skating start. Results revealed that throughout all 6 strides that were recorded, the male skaters had significantly greater hip abduction/adduction angles, suggesting a wider skating stride compared to their female counterparts, even though hip flexibility profiles were similar. Elite male skaters also had significantly more years of hockey playing experience than the females ($p < 0.05$), possibly resulting in a wider, more powerful skating stride being developed through more playing time. Male skaters also demonstrated greater knee flexion during the initial stance phase of the forward skating start and the latter strides as well (strides 4 and 6, $p < 0.05$). Similarly, Renaud et al. (2017) conducted a kinematic analysis of low and high caliber skaters during an ice hockey start using 3D motion capture on-ice. The study looked to identify vital movement patterns for maximal skate start acceleration that coaches and trainers could utilize as teaching cues for athlete development. Participants were 7 high caliber and 8 low caliber male ice hockey players (using playing experience as criteria). Skaters were required to perform three maximum efforts to start skating forward, but could not start using a crossover start. The study used a Vicon 10 camera and T-series t40S (two camera) motion capture system, setup on the arena ice surface. Participants were fitted with skin tight black suits and 24 reflective markers in order to capture ankle, knee, and hip kinematics. Stride length, stride width, and stride frequency were determined from data collected from the motion capture system. Four steps with both legs were analyzed for each trial. The step sequence began with Step1 OFF (S1OFF) and ended with Step 4 ON (S4ON). For the four steps of each trial, ice contact events (ON) and end of ice contact events (OFF) were identified through Visual3D by the velocity of the toe marker in the direction of forward progression and the jerk of the heel marker in the vertical direction (Renaud et al., 2017). Results revealed that high caliber skaters (time: 1.03s) performed the skate in significantly shorter time than the low calibre skaters (time: 1.20s). Step length and step width were similar between groups, along with most lower limb joint angles of the ankle, knee, and hip. However, high caliber skaters had higher stride rates, greater mean forward velocities and accelerations than the low caliber skaters. Lastly, interaction effects in stride phases between high caliber and low caliber skaters were detected in hip internal/external rotation for Leg 2 (p = 0.029). As well, there was a main stride phase effect in hip flexion/extension for Leg 1 (p = 0.002), there was a main effect for skating caliber in terms of knee flexion/extension for Leg 2, meaning that the high caliber skaters had an increased knee flexion, and extension, and hip rotation, flexion and extension after the first stride, compared to the low caliber skater (Renaud et al., 2017). Additionally, Bracko and Geithner (2010) reported that stride length/width was a better predictor of skating speed and velocity than stride rate, but stride rate was still important and highly correlated to both skating speed and velocity.

McPherson et al. (2004) determined the biomechanical characteristics of 30 male, 10-year-old hockey players to assess skating technique on ice. Players were required to complete a maximal acceleration test that was 18 m in length in order to assess skating technique while being recorded via two Panasonic CL-350 video cameras. In order to determine events in the skating cycle, push-off was defined as the first visible frame that the trailing skate blade left the ice, and touch-down was defined as the first visible frame that the leading skate blade made contact with the ice (McPherson et al., 2004). Strides 1 through 5 were used for analysis for each trial. All videos were digitized and then rendered on a computer to create a three-dimensional image that could be analyzed to determine kinematic information, including specific joint angles, velocity, and stride characteristics. Results revealed that there was a negative correlation between stride length and time to skate 6 meters, and that knee angle at touchdown, knee angle at push-off, and hip angle at touchdown were positively correlated (McPherson et al., 2004). The mean stride rate was 2.9 (± 0.29) strides/s and stride length continued to increase from stride 1 to 5 through the acceleration test.

2.6 Purpose

The primary purpose of the present study was to investigate the effect of a 12-session skate treadmill training intervention on stride mechanics in competitive youth ice hockey players (9.7 ± 0.5 y). The secondary purpose of the study was to investigate the effect of removing the training stimulus on retention of stride mechanics adaptations as a result of training. Stride mechanics were defined by the following variables: stride length (SL, in mm), stride frequency

(SF, in Hz), and select kinematic measures of the trunk, hip, and knee angles (°). The project received ethical clearance from the Brock University Research Ethics Board [File # 19-037].

2.7 Null Hypotheses

1. There are no significant differences in stride mechanics, namely SL (mm), SF (Hz) and select kinematic measures of the trunk, hip, and knee angles (°) upon completion of sessions 1-6 competitive youth ice hockey players (9.7 ± 0.5 y; n = 23), i.e.,

H_0: $A_{PRE1} = A_{POST1}$

2. There are no significant differences in stride mechanics, namely SL (mm), SF (Hz) and select kinematic measures of the trunk, hip, and knee angles (°) when the training stimulus is removed between sessions 6-7 in competitive youth ice hockey players (n = 23), i.e.,

H_0: $A_{POST1} = A_{PRE2}$

3. There are no significant differences in stride mechanics, namely SL (mm), SF (Hz) and select kinematic measures of the trunk, hip, and knee angles (°) upon completion of sessions 7-12 in competitive youth ice hockey players (n = 23), i.e.,

H_0: $A_{PRE2} = A_{POST2}$

4. There are no significant differences in stride mechanics, namely SL (mm), SF (Hz) and select kinematic measures of trunk, hip, and knee angles (°) upon completion of sessions 1-12 in competitive youth ice hockey players (n = 23), i.e.,

H_0: $A_{PRE1} = A_{POST2}$

2.8 Significance of Study

Information gathered from the present study will offer further understanding of the kinematic changes in skating stride mechanics in young ice hockey players following a sport-specific training intervention conducted on a skate treadmill. This study can inform the scientific and athletic community by adding to our knowledge regarding (a) effective training practices with respect to training stride mechanics on a skate treadmill, (b) the dose-response relationship between skate treadmill training and adaptations in stride mechanics as a result of training, and (c) the retention of adaptions in stride mechanics as a result of training following the removal of the training stimulus.

Chapter 3: Methods

3.1 Participants, Player Demographics and Equipment Characteristics

Twenty-three ice hockey players (9.7 ± 0.5 y) were recruited to participate in the study. The eligibility criteria consisted of the following: (i) no previous skate treadmill experience, (ii) self-reported as injury free, and (iii) playing the position of forward or defense in hockey. Participant characteristics, including age (y), height (cm), sitting height (cm), and weight (kg) were collected and are reported in Table 1.

Table 1

Participant Characteristics: Means (SD)

	Age (y)	Standing Height (cm)	Sitting Height (cm)	Weight (kg)
Mean ± SD	9.7 ± 0.5	141.3 ± 7.2	70.8 ± 3.9	35.6 ± 6.7

A questionnaire detailing hockey experience (y), level of current hockey experience (i.e., A, AA, AAA), and position (i.e., forward or defense) playing ice hockey was completed (Appendix A) and data reported in Table 2.

Table 2

Hockey Experience: Means (SD), Frequencies, and Percentages

	Hockey Experience (y)	Level of Hockey Experience				Playing Position	
		AAA	A	BB	House league/AE	Forward	Defense
Mean ± SD	5.5 ± 1.1						
Frequency		1	13	6	3	14	9
Percentage		4.3	56.5	26.1	13.0	60.9	39.1

A detailed description of the hockey equipment worn by participants during training (i.e., brand of skate boot, holder and blade) was also collected and are reported in Table 3.

Table 3

Participant Equipment Characteristics: Frequencies and Percentages

	Skate Brand		Holder Type		Blade Type		
	Bauer	**CCM**	**Tuuk**	**SteelBlade (SB)**	**Light Speed (LS-LS3+)**	**SB Stainless**	**Tuuk Stainless**
Frequency	17	6	17	6	12	6	5
Percentage	73.9	26.1	73.9	26.1	52.2	26.1	21.7

Participation in other sports was collected via a questionnaire prior to participation in the study (Appendix A). Participants were not restricted from playing other sports during the duration of the study given the knowledge that other sport training would not necessarily train skating stride mechanics; however, they were asked to keep an activity journal (Appendix B) detailing participation in other sports as well as to confirm that the participants did not participate in any additional training specific to the hockey-related skills and techniques. In terms of hockey, participants were asked not to participate any other hockey related technique training programs except team related on-ice practices/games during the duration of the study to limit the effect of other training stimuli on study outcomes. A qualitative analysis of the data detailing frequency of sport activity confirmed that 9 of the 23 (39%) participants participated in non-hockey related activities and none of the 23 participants participated in any additional hockey specific technique training during the study.

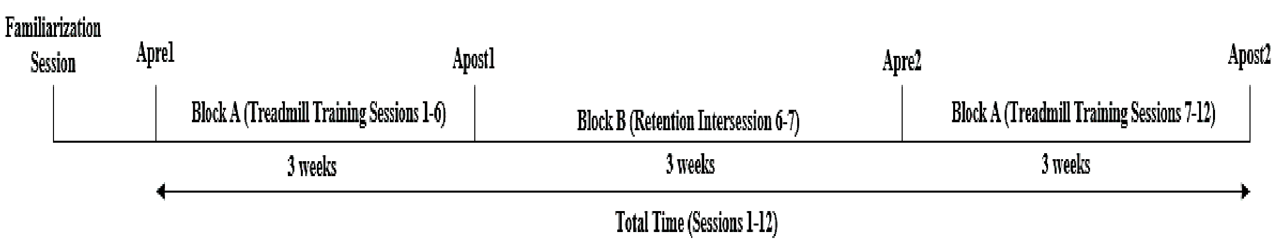
3.2 Study Design

An A-B-A, within-subject, quasi-experimental design was used to investigate the effect of a 12-session skate treadmill training intervention on stride mechanics in competitive youth ice hockey players. The quasi-experimental design allowed for a dose-response relationship to be examined between training and adaptations in stride mechanics, with each participant serving as their own control.

Dose was defined for the purpose of this study as number of exposures or volume of skate treadmill training time. Each session was 1-hour in duration; participants completed the training in an interval fashion in small groups (max of 6 athletes) in which the total time that each participant was on the treadmill was recorded. The response was defined as the adaptation or mechanical response to training (e.g., changes in SL (mm), SF (Hz), and select kinematic measures of the trunk, hip, and knee angles (°)). Sessions 1-6 and 7-12 were scheduled over 9 weeks (Figure 1), with 48-hours between sessions. Block A (sessions 1-6) included six, 1-hour skate treadmill training sessions, and included pre^1-post^1 (A_{pre1}-A_{post1}) anthropometric and vertical jump assessments. Block B (session 6-7) matched the duration of Block A, however the stimulus of skate treadmill training was removed. The second block A (sessions 7-12) included six, 1-hour skate treadmill training sessions, and again included pre^2-post^2 (A_{pre2}-A_{post2}) anthropometric and vertical jump assessments.

Figure 1

Study Timeline



3.3 Skate Treadmill

All training was conducted on a custom designed skate treadmill with a skating surface area of 3.60 m^2 (1.80 m wide × 2.00 m long). The surface is covered with a series of 82 polyethylene slats (size: X =1.80 m x Y = 0.06 m x Z = 0.015 m) prepared with a silicone spray to simulate the frictionless surface of real ice.

3.4 Participant Assent, Parental Consent and Questionnaire

Participant assent and parental consent forms (Appendix E) and a questionnaire (see Appendix A) were emailed to the parents of each participant for completion in the privacy of their own home and returned via email or collected by the researchers at the familiarization session.

3.5 Familiarization Session

A 1-hour familiarization session was completed prior to the first block of skate treadmill training (i) to introduce the participants to the lab and the researchers, and (ii) to collect anthropometrics measures including: standing height (cm), sitting height (cm), and weight (kg), and vertical jump height (cm), and (iii) familiarize participants with the skate treadmill. A standardized warm up of 200 skips was completed.

Standing height and sitting height (cm**)** were measured following the Canadian Society for Exercise Physiology (CSEP, 2013) protocol using a wall mounted measuring tape (34-106 Long Tape Measure, Stanley Black & Decker, New Britain, CT) and a rafter square. Participants were shoeless and were instructed to stand with heels, butt, upper back and head against the wall (CSEP, 2013). The measurement was recorded to the nearest 0.1 cm. Sitting height (cm) was measured by instructing the participants to sit with back and head against the wall, legs straight, feet together (CSEP, 2013). Each measurement was recorded to the nearest 0.1 cm. Weight (kg) was measured using a digital weight scale (Uline Industrial Platform Scale, Model No**.** H-670). The weight scale was tared to zero prior to each participant's measurement, and the value was recorded to the nearest 0.1 kg (CSEP, 2013).

Vertical jump height (cm) was measured using the *My Jump 2* app (Balsalobre, 2020). Participants were video-recorded while performing a counter-movement vertical jump in order to assess vertical jump height. Participants were video recorded using a dedicated lab device (Apple® iPad; Apple Inc, Cupertino, CA, USA) (iPad) in a frontal view at 120 Hz, at a distance of 1.5 m from the participant while performing a vertical jump in conjunction with the *My Jump 2* app (Balsalobre, 2020). The *My Jump 2* app (Balsalobre, 2020) calculated the flight time of the counter-movement jump by identifying the take-off and the landing frames of the video, and then transforming it into a jump height using the equation: $h = t^2$ x 1.22625, with h being the jump height in metres and t being the flight time of the jump in seconds (Bosco, Luhtanen, & Komi, 1983). Participants were instructed to perform a counter movement jump with hands on hips, keeping legs straight following take-off; bending the knee before landing or kicking the legs forward by flexing the hips was not permitted – such mistrials were not counted. Participants performed 3 trials of the jump protocol with 40 s of rest between trials, and the maximum height jumped was recorded and used for analysis.

Familiarization to the skate treadmill required that the participants wear their own ice hockey skates, and they were asked to have their blades sharpened for game-like conditions. Participants were fitted with a climbing-like harness and secured to an overhead safety gantry that eliminates any chance of falling, and safety and procedural instructions were provided to prevent any chance of injury to the athlete while on the skate treadmill. Familiarization to the skate treadmill included a second warmup conducted on the skate treadmill consisting of three, 20 s intervals of forward treadmill skating and a minimum of 8 min of treadmill exposure, including a number of low to moderate intensity, forward skating drills. A skating speed (10 mph or 16 km/h) and incline (5 °) with respect to age and ability of the participant cohort was selected for use during each of the stride mechanics assessments or video collections.

3.6 Training Intervention

All skate treadmill training sessions were 1-hour in duration and instructed by the same experienced trainer who exemplified a high level of knowledge of forward skating stride mechanics and skate treadmill training. Each session consisted of the standardized dryland warm-up of 200 skips and 45 min of skate treadmill training. Consistent with familiarization, participants wore their own skates, sharpened for game like conditions, were fit with a climbing-like harness, and secured to an overhead safety gantry. A second warmup was conducted on the treadmill consisting of three, 20 s intervals of forward treadmill skating. Training sessions consisted of 10-16 forward skating drills, each lasting 5-20 s at specific speeds and inclines and maintained a work:rest ratio of 1:5. Training complexity and variety was provided through the use of different forward skating and forward C-cut (scullies) drills throughout the training intervention. Treadmill time (s), speed (mph), incline (°), and complexity (skating without sticks and pucks vs. skating with sticks and pucks) were used to establish intensity and prescribe a progressive overload. The training stimulus was low to moderate intensity, and was gauged to elicit a mechanical adaptation not necessarily a physiological or fitness effect. Training volume was defined as the amount of work being done on the treadmill and was calculated as the sum of the durations (in seconds) of each drill for each session. All training sessions were supervised and instructed by the same experienced trainer who exemplified a high level of knowledge of forward skating stride mechanics and skate treadmill training. The Block A training protocol has been outlined in Table 4. Following each individual training session, a review of age and ability appropriateness of the training protocol was conducted to determine the ability of the participants to progress.

Table 4

Frequency, Intensity, Time, and Type (FITT) of Block A Training Protocol

Block A Training Protocol	
Frequency	2x per week
Duration	9 weeks
Intensity	drill time (s), treadmill speed (mph) & treadmill incline (degrees)
Overload	Progressive overload gauged by an increase in time (s), speed (mph), incline (degrees), and complexity
Type	Skate Treadmill Training
Time	1 hour per groups of 6
Volume	Sum of the length of each drill in seconds

3.7 Adherence

Due to the nature of the study, complete and consistent attendance was required for all participants. If a participant missed a session, a make-up session was scheduled at the end of the training after session 6 or session 12. If a participant was not able to attend the make-up session, they were eliminated from the study and did not receive further training.

3.8 Stride Mechanics Video Collection

Participants were video recorded for fifteen consecutive strides after the skate treadmill warm-up using a dedicated lab device (Apple® iPhone 6; Apple Inc, Cupertino, CA, USA) setup on a tripod. Recording was conducted while skating at a treadmill speed (10 mph or 16 km/h) and incline (5 °) at 60 frames per second in a sagittal view, at a distance of 2.40 m from the left edge of the skating surface to ensure an adequate image size for analysis. Speed and incline were determined during the familiarization session as an appropriate skating speed and incline with respect to age and ability of the participant cohort, for fifteen consecutive strides. If the participant tripped, stumbled or fell, the participant was provided with adequate rest before repeating the fifteen-stride interval.

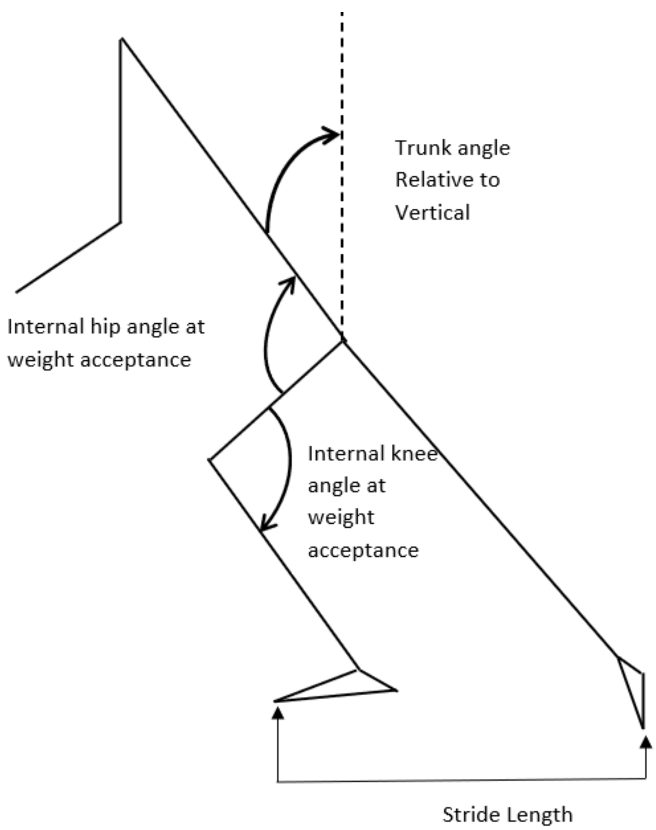
3.9 Video Processing and Analysis

Video recordings of each participant were individually coded and uploaded into the wrnch^{TM} motion analysis software (wrnch.ai., Montreal, QC) for digitizing. Three-dimensional coordinates were provided by the wrnch^{TM} motion analysis software to construct a three-dimensional model. The three-dimensional model was scaled using participants leg length (cm), calculated from the difference between participants standing height (cm) and sitting height (cm) in Python^{TM} (version 3.7, Python Software Foundation, Wilmington, Delaware, United States) open-source software. Coordinate data were filtered (using a low-pass 2nd order Butterworth filter with a cut-off frequency of 15 Hz) and processed using Python^{TM}.

Coordinate data was used to calculate stride mechanics variables defined as stride length (SL, in mm), stride frequency (SF, in Hz), and select angles of the trunk, hip, and knee (°) (Figure 2). Ten of the fifteen recorded strides were used for the purpose of analysis. SL (mm) was determined by calculating the difference in horizontal displacements (in mm) between the left toe marker when the left toe was in maximum displacement in the x-direction anteriorly (weight acceptance) to the left toe marker when the left toe was at maximum displacement in the posterior x-direction (following toe-off) during the same stride (see Figure 2). SF (strides per second/Hz) was determined by identifying the number of the frame in the recording at the point of the 10th stride, divided by the number of left foot weight acceptance events that occurred and divided by the frame rate of the recording (60 frames per second) to determine stride rate in Hz (strides/second). Trunk angle (°), hip angle (°), and knee angle (°) were calculated using the dot product method. Trunk, hip, and knee angle (°) at weight acceptance were determined using the frame of maximum displacement of the left toe-marker in the anterior (positive) x-direction during the glide phase of the stride. Trunk, hip, and knee angles (°) following toe-off were determined using the frame of maximum displacement of the left toe marker in the posterior (negative) x-direction following the initial weight acceptance of that stride. SL (mm), SF (Hz), trunk angle (°), hip angle (°), and knee angle (°) were reported as mean values over 10 strides.

Figure 2

Stride length, trunk, hip, and knee angle protocols for kinematic measurements



3.10 Statistical Analysis

Statistical Package for the Social Sciences (SPSS) statistical software (SPSS for Windows, Version 26, 2019. Chicago, Illinois) was used to analyze the data. Descriptive statistics, including mean (M) and standard deviation (±SD) were calculated for all variables. Multiple Repeated Measures Analysis of Variances (ANOVA) were conducted to determine if a significant difference existed in stride length (SL, in mm), stride frequency (SF, in Hz), trunk angle (º) at weight acceptance and following toe-off, hip angle (º) at weight acceptance and following toe-off, and knee angle (º) at weight acceptance and following toe-off across all four time frames. Specifically, pre-post training sessions 1-6 (A_{pre1}-A_{post1}), pre-post sessions 6-7 (A_{post1}-A_{pre2}), pre-post training sessions 7-12 (A_{pre2}-A_{post2}), and pre-post training sessions 1-12 (A_{pre1}-A_{post2}).

Bonferroni *post-hoc* tests were conducted to determine the location of any differences identified through each ANOVA. Pearson product–moment correlations were used to examine relationships between SL (mm) and SF (Hz), between SL (mm) and trunk angle (º) at weight acceptance and following toe-off, between SL (mm) and hip angle (º) at weight acceptance and following toe-off, and between SL (mm) and knee angle (º) at weight acceptance and following toe-off at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2}. Statistical significance was set at $p \leq 0.05$.

Chapter 4: Results

4.1 Quantification of Skate Treadmill Training

Twenty-three participants completed twelve 1-hour training sessions in small groups of 4-6 participants, conducted in an interval-type fashion. The skate treadmill training protocol was age and ability appropriate, and included a progressive overload. Sessions included 10-16 drills, each lasting 5-20 s, with speeds ranging from 4-12 mph (6.4-19.3 km/h) and inclines from 2-14º. Training volume was calculated as the sum of the durations (in seconds) of each drill and totalled by each session. Training volume increased from 155 s (2 min: 35 s) during session 1 to 235 s (3 min: 55 s) during sessions 4-12. Total training volume over twelve sessions was calculated as the sum of each session, with training sessions 1-6 being 1190s (19 min: 50 s), no training between sessions 6-7, and training sessions 7-12 involving 1410s (23 min: 30 s), resulting in a grand total of 2600 s (43 min: 20 s) of treadmill training time.

4.2 Pre-Post Analyses

All variables, including anthropometric variables [standing height (cm), sitting height (cm), weight (kg)], vertical jump height (cm), and stride mechanics variables [stride length (SL, in mm), stride frequency (SF, in Hz), trunk angle (º) at weight acceptance and following toe-off, hip angle (º) at weight acceptance and following toe-off, and knee angle (º) at weight acceptance and following toe-off], were analyzed across four time frames; (i) pre-post training sessions 1-6 (A_{pre1} -A_{post1}), (ii) pre-post sessions 6-7 (A_{post1}-A_{pre2}), (iii) pre-post training sessions 7-12 (A_{pre2}-A_{post2}), and (iv) pre-post training sessions 1-12 (A_{pre1}-A_{post2}).

4.2.1 Anthropometric Variables and Vertical Jump Height

Means and standard deviations of all anthropometric and vertical jump height variables across all four time frames were calculated and reported in Table 5. Multiple Repeated Measures

Analysis of Variances (ANOVAs) with a Greenhouse-Geisser correction revealed no significant difference in anthropometric variables [sitting height (cm) and weight (kg)], and vertical jump height (cm) between pre-post training sessions 1-6 (A_{pre1}-A_{post1}), pre-post sessions 6-7 (A_{post1}-A_{pre2}), pre-post training sessions 7-12 (A_{pre2}-A_{post2}), and pre-post training sessions 1-12 (A_{pre1}-A_{post2}). Unexpectantly, a significant difference was revealed in standing height (cm) pre-post the twelve session training intervention ($F(2.587, 56.923) = 12.943$, $p < 0.05$. *Post hoc* tests using a Bonferroni correction revealed a significant difference in mean standing height between A_{pre1} to A_{post2} (141.3 vs. 142.4 cm; $p < 0.05$). However, there was no significant difference in standing height (cm) between A_{pre1} to A_{post1} and between A_{pre2} to A_{post2} ($p < 0.05$). A further analysis of raw scores in standing height revealed that the difference A_{pre1} to A_{post2} was 1.1 cm and sitting height was 0.4 cm meaning that participants leg length could have increased by 0.7 cm, however this minimal change would not have affected data analysis or interpretation.

Table 5

Anthropometric Variables and Vertical Jump Height at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Means ± SD)

	A_{pre1}	A_{post1}	A_{pre2}	A_{post2}
Standing Height (cm)	141.3 ± 7.2	141.5 ± 6.9	141.7 ± 7.0	142.4 ± 7.0*
Sitting Height (cm)	70.9 ± 3.9	71.1 ± 3.7	71.4 ± 5.1	71.3 ± 3.9
Weight (kg)	35.6 ± 6.7	35.5 ± 6.4	35.7 ± 6.3	35.8 ± 6.5
Vertical Jump Height (cm)	23.5 ± 3.5	22.6 ± 4.3	22.2 ± 4.3	22.3 ± 4.4

Note. ***** Indicates a Significant Difference from A_{pre1}

4.2.2 Kinematic Variables

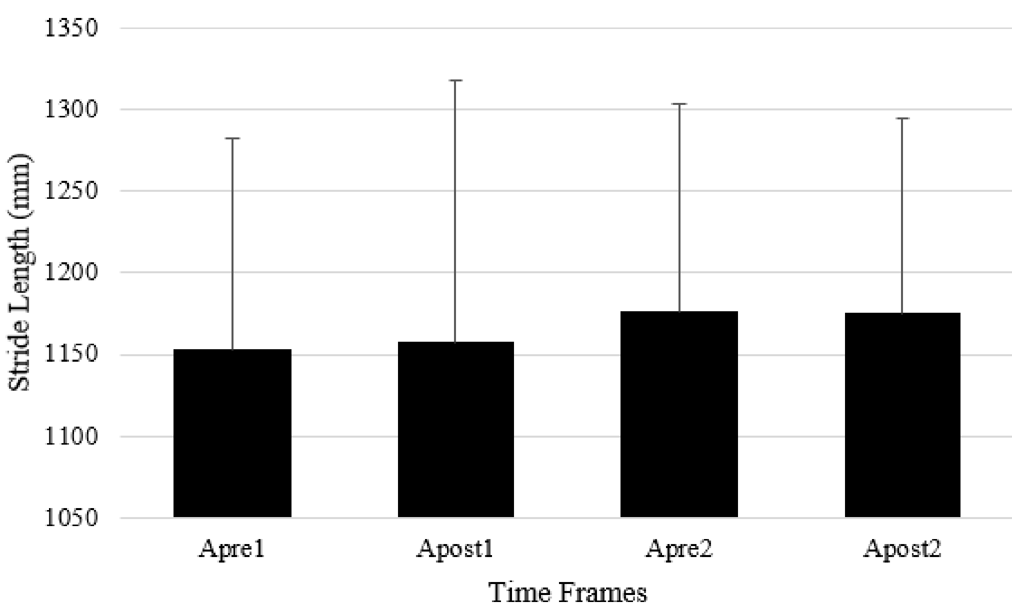
Means and standard deviations of all kinematic variables across all four time frames were calculated and reported in Table 6. Multiple Repeated Measures ANOVAs with a Greenhouse-

Geisser correction revealed no significant differences in stride length (SL, in mm), stride frequency (SF, in Hz), hip angle at weight acceptance, and knee angle at weight acceptance, but did reveal significant differences in trunk angle at weight acceptance and following toe-off, hip angle following toe-off and knee angle following toe-off across the four time frames (°). Absolute difference (± SE) and percent change of all kinematic variables across the four time frames were also calculated and reported in Table 7.

Although, no significant difference in mean stride length (mm) pre-post the twelve session training intervention were revealed, Figure 3 illustrates very consistent directional changes in stride length from A_{pre1}-A_{post2}, meaning that stride length (mm) increased as a result of the training intervention.

Figure 3

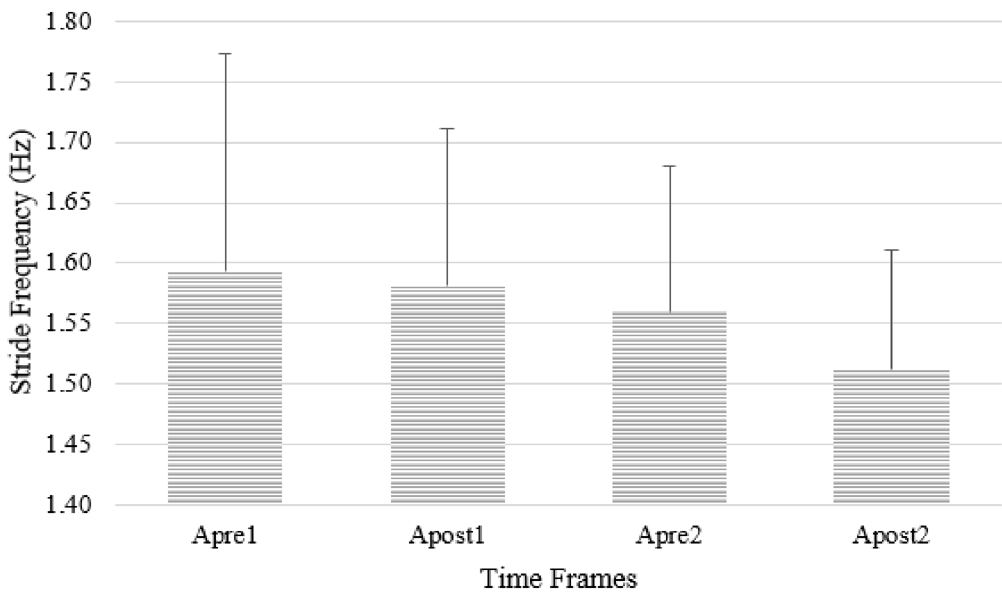
Stride Length at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Means ± SD)



Similar to stride length, although no significant difference in mean stride frequency (Hz) pre-post the twelve session training intervention was revealed, Figure 4 illustrates very consistent directional changes in stride frequency from A_{pre1}-A_{post2}, meaning that stride frequency (Hz) decreased as a result of the training intervention.

Figure 4

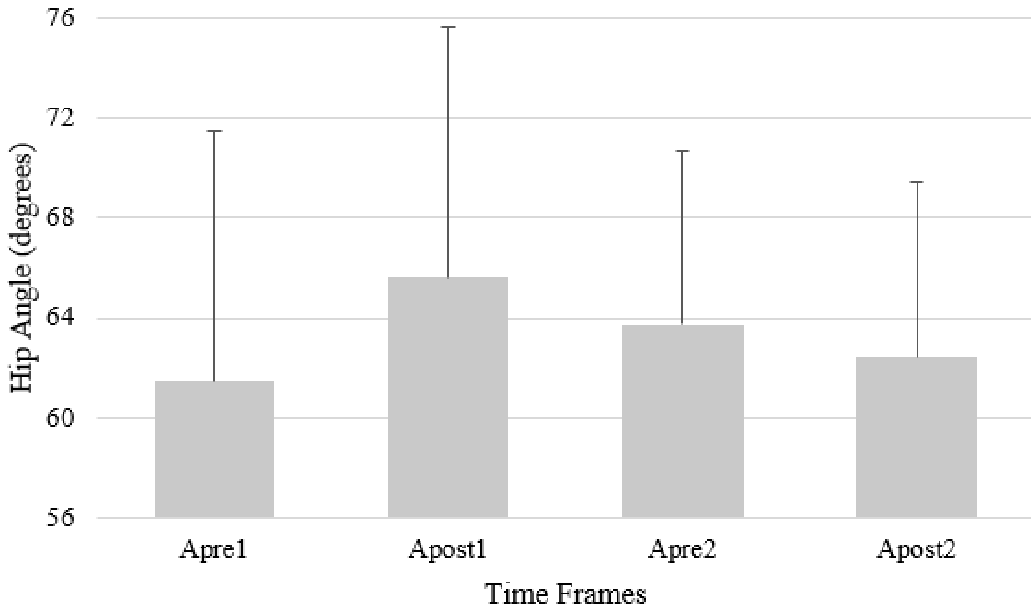
Stride Frequency at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Means ± SD)



Although, no significant difference in mean hip angle (º) at weight acceptance pre-post the twelve session training intervention, Figure 5 illustrates very consistent directional changes in hip angle at weight acceptance from A_{post1}-$A_{post2,}$ meaning that hip flexion (º) increased as a result of the second six sessions of the training intervention.

Figure 5

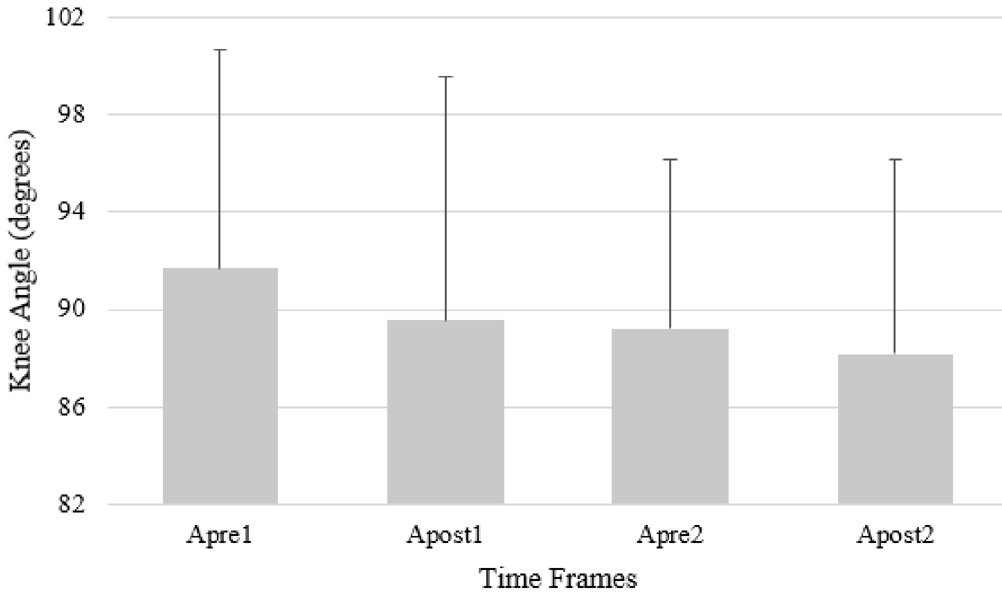
Hip Angle at Weight Acceptance at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Means ± SD)



Although, no significant difference in mean knee angle (º) at weight acceptance pre-post the twelve session training intervention, Figure 6 illustrates very consistent directional changes in knee angle at weight acceptance from A_{pre1}-A_{post2}, meaning that knee flexion (º) increased as a result of the training intervention.

Figure 6

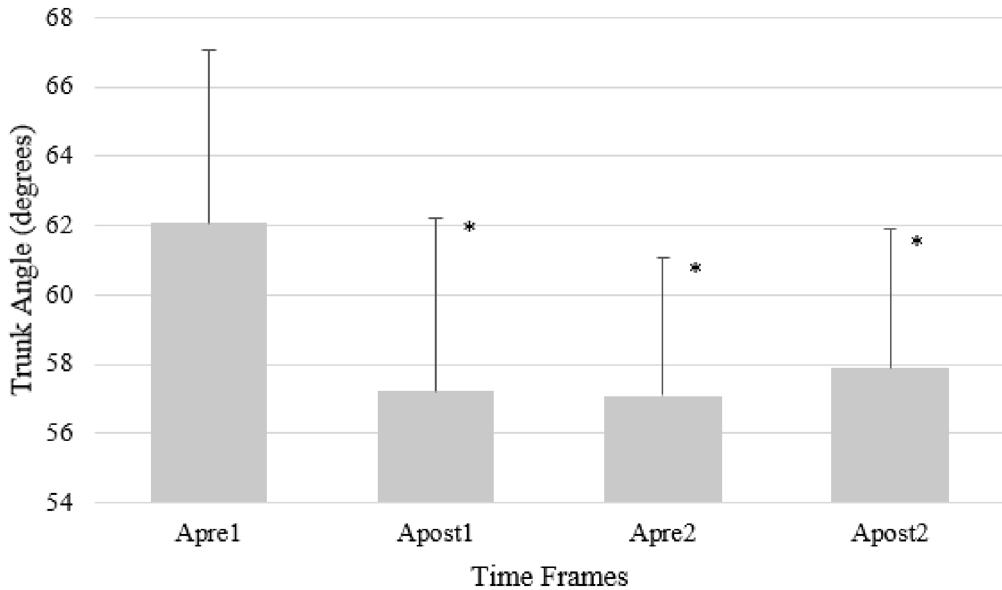
Knee Angle at Weight Acceptance at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Means ± SD)



A Repeated Measures ANOVA with a Greenhouse-Geisser correction revealed a significant difference in mean trunk angle (º) at weight acceptance pre-post the twelve session training intervention ($F(2.628, 57.814) = 7.405$, $p < 0.05$, $n^2_p = 0.25$. *Post hoc* tests using a Bonferroni correction revealed a significant difference in trunk angle for pre-post training sessions 1-6 (A_{pre1}-A_{post1}) (62 ± 5º vs 57 ± 5º; $p < 0.05$) and pre-post training sessions 1-12 (A_{pre1}-A_{post1}; $p < 0.05$). However, trunk angle at weight acceptance for pre-post sessions 6-7 (A_{post1}-A_{pre2}) was not significantly different ($p < 0.05$). Trunk angle at weight acceptance was not significantly different in pre-post training sessions 7-12 (A_{pre2}-A_{post2}) ($p < 0.05$), meaning that the participants developed a more upright forward leaning upper body position in the first six sessions, and maintained this position throughout the remainder of the training intervention (Figure 7).

Figure 7

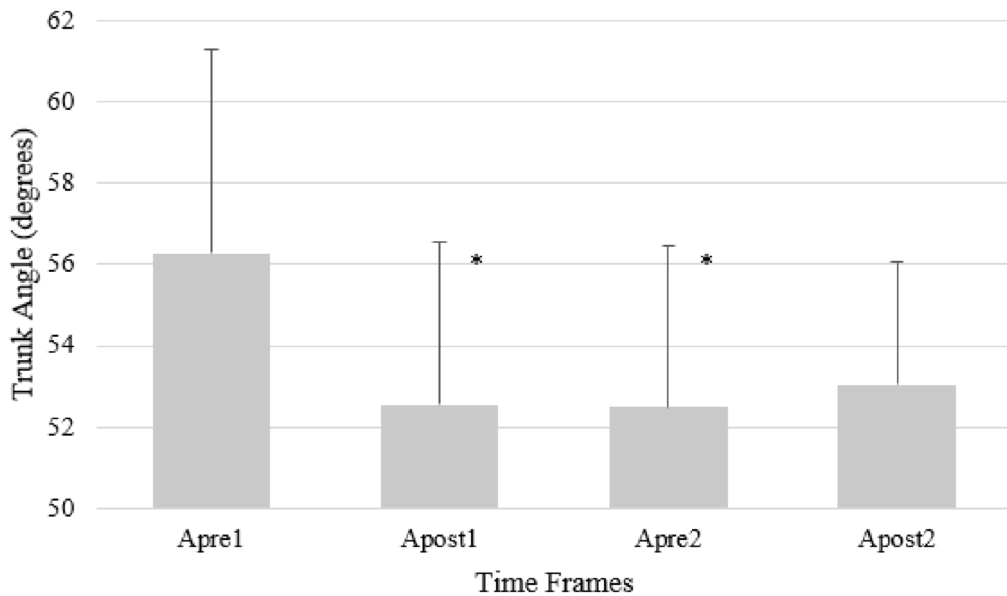
Trunk Angle at Weight Acceptance at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Means ± SD)



A Repeated Measures ANOVA with a Greenhouse-Geisser correction revealed a significant difference in mean trunk angle (º) following toe-off for pre-post the twelve session training intervention (F(2.101, 46.220) = 6.546, $p < 0.05$, $n^2_p = 0.23$. *Post hoc* tests using a Bonferroni correction revealed a significant difference in trunk angle following toe-off for pre-post training sessions 1-6 (A_{pre1}-A_{post1}) (56 ± 5º vs 53 ± 4º; $p < 0.05$). However, there was no significant difference revealed in mean trunk angle following toe-off for pre-post sessions 6-7 (A_{post1}- A_{pre2}) ($p < 0.05$). Trunk angle following toe-off was not significantly different for pre-post training sessions 7-12 (A_{pre2}-A_{post2}) ($p < 0.05$). meaning that this was consistent with the previous pattern illustrated in Figure 7, participants developed a more upright forward lean in the first six sessions and maintained throughout the remainder of the intervention (Figure 8).

Figure 8

Trunk Angle Following Toe-off at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Means ± SD)

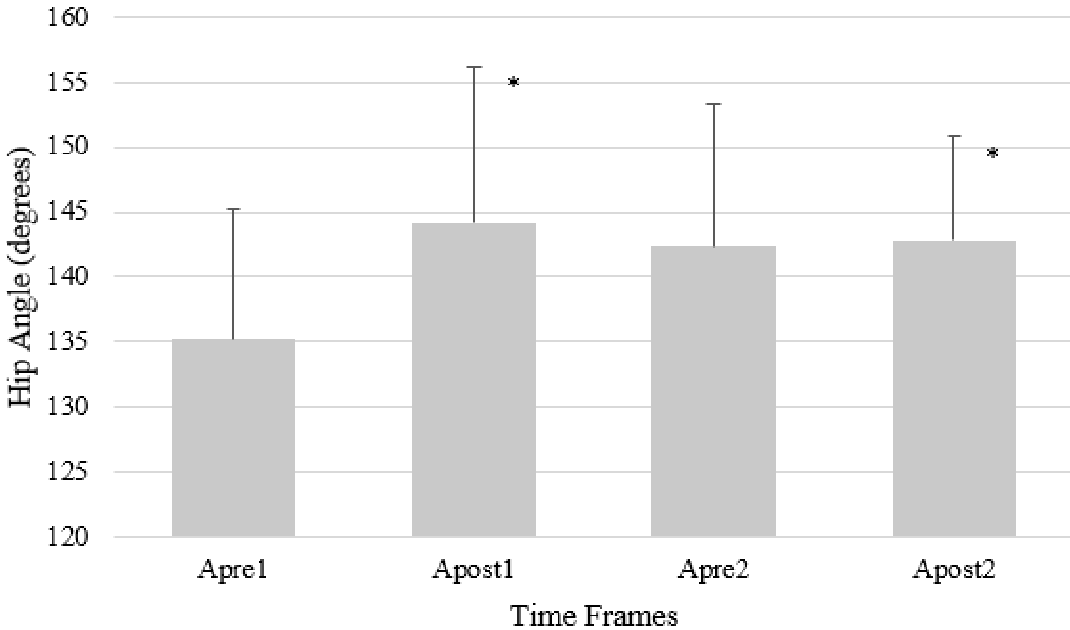


Note: * Indicates a significant difference from A_{pre1}.

A Repeated Measures ANOVA with a Greenhouse-Geisser correction revealed a significant difference in mean hip angle (º) following toe-off pre-post the twelve session training intervention ($F(2.543, 55.947) = 6.443$, $p <0.05$, $n^2_p = 0.23$. *Post hoc* tests using a Bonferroni correction revealed a significant difference in mean hip angle following toe-off for pre-post training sessions 1-6 (A_{pre1}-A_{post1}) (135 ± 10º vs 144 ± 12º; $p < 0.05$) and pre-post training sessions 1-12 (A_{pre1}-A_{post2}) (135 ± 10º vs 143 ± 8º; $p < 0.05$). However, there was no significant difference revealed in mean hip angle following toe-off for pre-post sessions 6-7 (A_{post1}-A_{pre2}) ($p < 0.05$). Mean hip angle following toe-off was not significantly different for pre-post training sessions 7-12 (A_{pre2}-A_{post2}) ($p < 0.05$), meaning that there was an increase in hip extension after the first six sessions and minimal changes throughout the remainder of the intervention (Figure 9).

Figure 9

Hip Angle Following Toe-off at A_{pre1}, A_{post1}, A_{pre2}, A_{post2} (Means ± SD)

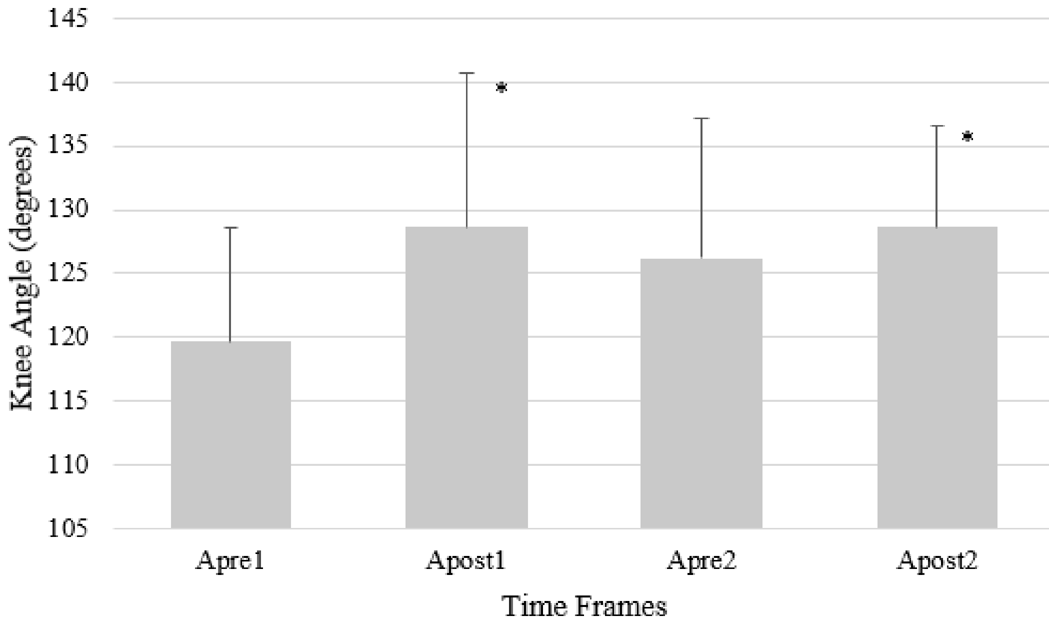


Note: * Indicates significant difference from A_{pre1}.

A Repeated Measures ANOVA with a Greenhouse-Geisser correction revealed a significant difference in mean knee angle (º) following toe-off pre-post the twelve session training intervention ($F(2.829, 62.242) = 7.987$, $p = 0.000$, $n^2_p = 0.27$. *Post hoc* tests using a Bonferroni correction revealed a significant difference in mean knee angle (º) following toe-off for pre-post training sessions 1-6 (A_{pre1}-A_{post1}) (120 ± 9º vs 129 ± 12º; $p < 0.05$) and pre-post training sessions 1-12 (A_{pre1}-A_{post2}) (120 ± 9º vs 129 ± 8º; $p < 0.05$). However, there was no significant difference revealed in mean knee angle following toe-off for pre-post sessions 6-7 (A_{post1}- A_{pre2}) ($p < 0.05$). Mean knee angle following toe-off was not significantly different for pre-post training sessions 7-12 (A_{pre2} to A_{post2}) ($p < 0.05$), meaning that there was an increase in knee extension after the first six sessions but minimal changes throughout the remainder of the intervention (Figure 10).

Figure 10

Knee Angle Following Toe-off at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Means ± SD)



Note: * Indicates significant difference from A_{pre1}.

Table 6

Kinematic Variables at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Means ± SD)

	A_{pre1}	A_{post1}	A_{pre2}	A_{post2}
Stride Length (SL·mm)	1153 ± 130	1158 ± 160	1176 ± 127	1175 ± 120
Stride Frequency (SF·Hz)	1.59 ± 0.18	1.58 ± 0.13	1.56 ± 0.12	1.51 ± 0.10
Trunk Angle at Weight Acceptance (º)	62 ± 5	57 ± 5*	57 ± 4*	58 ± 4*
Trunk Angle following Toe-off (º)	56 ± 5	53 ± 4*	53 ± 4*	53 ± 3
Hip Angle at Weight Acceptance (º)	62 ± 10	66 ± 10	64 ± 7	63 ± 7
Hip Angle following Toe-off (º)	135 ± 10	144 ± 12*	142 ± 11	143 ± 8*
Knee Angle at Weight Acceptance (º)	92 ± 9	90 ± 10	89 ± 7	88 ± 8
Knee Angle following Toe-off (º)	120 ± 9	129 ± 12*	126 ± 11	129 ± 8*

Note. * Indicates a Significant Difference from A_{pre1}

Table 7

Absolute Difference (± SE) and Relative Change (%) in Kinematic Variables Across the Four Time Frames

	Absolute and	Absolute and	Absolute and	Absolute and

	Relative Change (%) A_{pre1} - A_{post1}	**Relative Change (%) A_{post1} – A_{pre2}**	**Relative Change (%) A_{pre2} - A_{post2}**	**Relative Change (%) A_{pre1} - A_{post2}**
Stride Length (SL·mm)	5 ± 22 (*0.4*)	18 ± 22 (*1.5*)	1 ± 20 (*0.1*)	22 ± 15 (*1.9*)
Stride Frequency (SF·Hz)	0.01 ± 0.04 (*0.6*)	0.02 ± 0.03 (*1.3*)	0.05 ± 0.03 (*3.2*)	0.08 ± 0.03 (*5.0*)
Trunk Angle at Weight Acceptance (º)	5 ± 4 (*8.0*)*	0 ± 1 (*0.0*)	1 ± 1 (*1.7*)	4 ± 1 (*6.4*)*
Trunk Angle following Toe-off (º)	3 ± 1 (*5.4*)*	0 ± 1 (*0.0*)	0 ± 1 (*0.0*)	3 ± 1 (*5.4*)
Hip Angle at Weight Acceptance (º)	4 ± 2 (*6.5*)	2 ± 2 (*3.0*)	1 ± 2 (*1.6*)	1 ± 2 (*1.7*)
Hip Angle following Toe-off (º)	9 ± 2 (*6.7*)*	2 ± 2 (*1.3*)	1 ± 2 (*0.7*)	8 ± 2 (*5.9*)*
Knee Angle at Weight Acceptance (º)	2 ± 2 (*2.1*)	1 ± 2 (*1.1*)	1 ± 1 (*1.1*)	4 ± 2 (*4.3*)
Knee Angle following Toe-off (º)	9 ± 2 (*7.5*)*	3 ± 2 (*2.3*)	3 ± 2 (*2.4*)	9 ± 2 (*7.5*)*

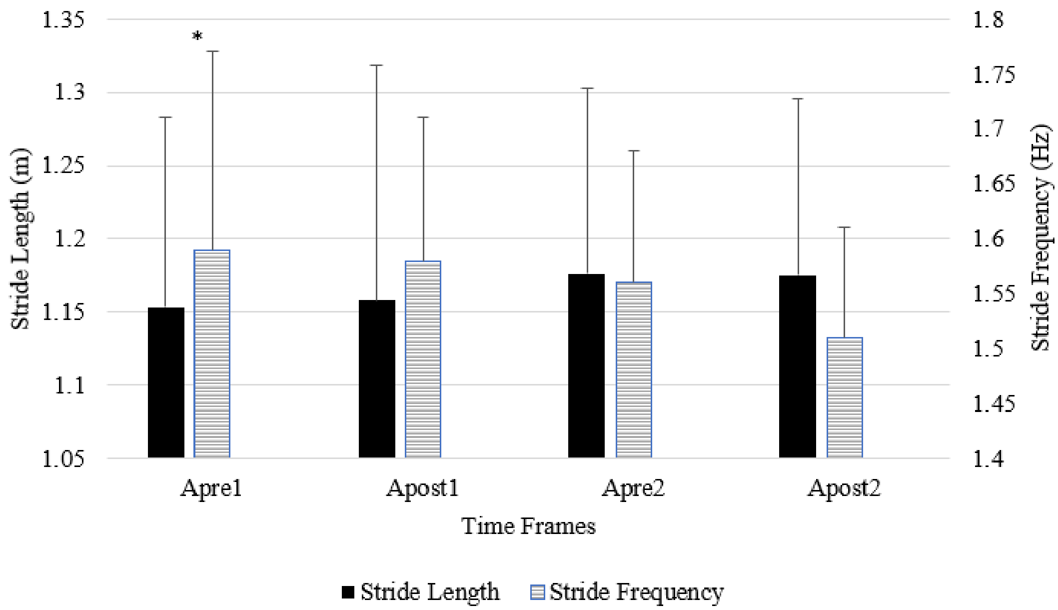
Note. * Indicates Significant Difference. *Note:* Percentage change highlighted in *italics*.

4.3 Pearson Product Moment Correlations

A Pearson product moment correlation analysis was conducted to determine the relationship between stride length (SL, in mm) and stride frequency (SF, in Hz) at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2}. The analysis revealed a significant inverse correlation between SL and SF at A_{pre1}, $r = -0.44$, $p < 0.05$; however, no significant correlations were found at A_{post1}, A_{pre2}, or A_{post2}, as illustrated in Figure 11.

Figure 11

Stride Length and Stride Frequency at A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Means ± SD)



Note. * Indicates significant correlation. This figure illustrates the inverse relationship between Stride Length (SL) and Stride Frequency (SF) as SL increases, SF decreases.

Pearson product–moment correlations were also conducted to determine the relationships between SL, trunk angle at weight acceptance and following toe-off, between SL and hip angle at weight acceptance and following toe-off, and between SL and knee angle at weight acceptance and following toe-off for A_{pre1}, A_{post1}, A_{pre2}, and A_{post2} (Table 8). A positive relationship was revealed at A_{pre1}, including a significant correlation between SL and trunk angle at weight acceptance (r = 0.42, $p < 0.05$). An inverse relationship and a number of positive relationships were revealed, including significant correlations at A_{post1} between SL and trunk angle following toe-off (r = -0.44, $p < 0.05$), hip angle following toe-off (r = 0.60, $p < 0.05$), and knee angle following toe-off (r = 0.55, $p < 0.05$). A significant positive correlation was revealed at A_{post2} between SL and knee angle at weight acceptance (r = 0.60, $p < 0.05$). No significant correlations were revealed between SL and hip angle at weight acceptance ($p < 0.05$).

Table 8

Pearson Product Moment Correlations at A_{pre1}, A_{post1}, A_{pre2}, A_{post2}

	A_{pre1}	A_{post1}	A_{pre2}	A_{post2}
Stride length and Stride Frequency	-0.44*	-0.21	-0.24	-0.31
Stride Length and Trunk Angle at Weight Acceptance	0.42*	0.02	0.08	-0.21
Stride Length and Trunk Angle Following Toe-off	0.15	-0.44*	-0.44*	-0.28
Stride Length and Hip Angle at Weight Acceptance	-0.36	-0.15	-0.05	0.19
Stride Length and Hip Angle Following Toe-off	0.23	0.60*	0.38	0.30
Stride Length and Knee Angle at Weight Acceptance	0.11	0.39	0.58*	0.60*
Stride Length and Knee Angle Following Toe-off	0.27	0.55*	0.24	0.04

Note: * Indicates a significant correlation.

Chapter 5: Discussion

Research investigating the biomechanics of a forward skating stride, commonly referred to as stride mechanics, has primarily focused on an adult male cohort, skating on ice, and an analysis of only select phases of the stride, such as acceleration of a forward skating stride (Marino, 1974; Pearsall, Turcotte, Murphy, 2000; Pearsall et al., 2001; Renaud et al., 2017; Shell et al., 2017; Upjohn et al., 2008). Limited research has explored the use of sport specific infrastructure, namely the use of a skate treadmill and sport-specific training in developmental ice hockey players. Lockwood & Jackson (2010) developed an age and skill appropriate model of skate treadmill training throughout the established stages of LTAD for the sport of ice hockey. Harris (2010) implemented the model in 14-year-old competitive ice hockey players, exploring both physiological and mechanical responses to skate treadmill training. Tidman (2015) also explored the use of skate treadmill activity to quantify biomechanical variables representing stride mechanics in youth players. Building upon these fundamental studies, a dose-response relationship between training and adaptations in stride mechanics, or more specifically, addressing the effectiveness of skate treadmill training in youth ice hockey players has not been explored.

Twenty-three youth ice hockey players completed twelve 1-hour skate treadmill training sessions scheduled over 9 weeks. Training was conducted in small groups of 4-6 athletes per session, exposing each participant to an average of 43.33 minutes (43 min: 20 s) of training over the 12 sessions. A progressive overload was implemented by increasing incline (°), speed (mph), complexity of skills, and volume (s) of training per session. Treadmill incline (°) ranged from 2 - 14°, treadmill speed (mph) ranged from 4 - 12 mph (6.4 - 19.3 km/h), and complexity included forward skating that progressively incorporated sticks and pucks. Training volume increased from 155 s (2 min: 35 s) in session 1 to 235 s (3 min: 55 s) in sessions 4 - 12 consistently; as the participants became more comfortable on the skate treadmill, they were able to complete more drills within a one-hour training session.

Pre-post analyses of selected stride mechanics, measured across the four time frames (i.e., sessions 1-6, sessions 6-7, sessions 7-12, and sessions 1-12), were used to identify and quantify changes in stride mechanics as a result of the skate treadmill training intervention. Being that the participants did not exhibit changes in growth and/or development (i.e., sitting height or vertical jump height) as revealed through pre-post anthropometric and vertical jump measures, and given the relationships determined from the study, it would seem sound to conclude that the observed changes were a result of the training intervention. Furthermore, all participants were required to complete questionnaires in order to confirm that, they did not participate in other skating skill-related technical training that might have contributed to changes in stride mechanics or mechanical adaptations.

In an attempt to quantify the effectiveness of a skate treadmill (infrastructure) with sport-specific training (expertise) on stride mechanics, a dose-response analysis was conducted on all variables, namely SL (mm), SF (Hz), and the select kinematic measures of trunk angle (°), hip angle (°), and knee angle (°) across the four time frames (i.e., sessions 1-6, sessions 6-7, sessions 7-12 and sessions 1-12). Block A (sessions 1-6), representing the initial exposure to skate treadmill training, revealed the greatest changes or percent improvements. During training sessions 1-6, participants were exposed to 1190s (19 mins: 50 s) of treadmill training. An analysis of kinematic changes pre-post this initial exposure revealed a 0.4 % increase in SL (mm), a 0.6 % decrease in SF (Hz), an 8.0% decrease in trunk angle at weight acceptance (°), and a 5.4% decrease in trunk angle following toe-off (°). Furthermore, differences in hip and knee flexion at weight acceptance (6.5% increase, in °; 2.1% increase, in °), were coordinated with hip and knee angles or extension following toe-off (6.7% increase, in °; 7.5% increase, in °). Changes elicited in Block A could be interpreted as positive adaptations in stride mechanics, supporting the development of a more effective skating stride.

Block B (sessions 6-7), defined as the time when the training stimulus was removed, participants revealed minimal changes in kinematic variables in comparison to the improvements seen in the initial Block A. For example, a 1.4% increase in SL (mm), a 1.3% decrease in SF (Hz), a 0.0% change in trunk angle at weight acceptance and following toe-off (°), a 3.0% decrease in hip flexion and 1.1% increase in knee flexion at weight acceptance (°), and a 1.3% decrease in hip extension and a 2.3% decrease in knee extension following toe-off (°). Minimal changes elicited in Block B could be interpreted as a retention of previous changes, with no significant loss in previously acquired stride mechanics.

The second Block A (sessions 7-12) of exposure to skate treadmill training revealed minimal changes in further improvement. During the second Block A of training, participants were exposed to an additional 1410s (23 min: 30 s) of treadmill training. An analysis of kinematic changes pre-post the second exposure revealed a 0.1% change in SL, a 3.2% decrease in SF, a 1.7% change trunk angle at weight acceptance, a 0.0% change in trunk angle following toe-off, a 1.6% decrease in hip flexion and a 1.1% increase in knee flexion at weight acceptance, and a 0.7% increase in hip extension and a 2.4% increase in knee extension following toe-off. Although the volume of the second Block A training period (1190 s or 19 min: 20 s) was greater than the first Block A (1410 s or 23 min:30 s), the initial six training sessions elicited greater differences in stride mechanics. These results are consistent with a habituation study conducted by Lockwood and Frost (2007) that found six sessions of exposure to the skate treadmill elicited significant changes in the stride mechanics of the participants.

Accumulatively across training sessions 1-12, participants were exposed to a total volume of 2600s (43 min: 20 s) of skate treadmill training, which elicited a 1.9% increase in SL, a 5.0% decrease in SF, a 6.4% decrease in trunk angle at weight acceptance, a 5.4% decrease in trunk angle following toe-off (°), a 1.7% increase in hip flexion and 4.3 % in knee flexion at weight acceptance, a 5.9% increase in hip extension, and a 7.5% increase in knee extension following toe-off. Increases in knee flexion at weight acceptance and corresponding increases in hip and knee extension at toe off, indicate that participants were utilizing a greater range of motion in the lower limb, which likely contributed to the participants developing an increased stride length. Standard deviations for trunk, hip and knee angles decreased pre-post sessions 1-12, indicating that participants revealed less variability in their trunk movements and executed technique with less variability in their stride.

As described above, the changes in each kinematic variable have been identified independently; however, in order to understand the effectiveness of the collective changes in terms of full body movement mechanics, an interpretation of the relationships between the various kinematic variables was also conducted and interpreted. Directional changes revealed an inverse relationship between SL (mm) and SF (Hz), meaning that as SL increased, SF decreased. SL and SF are two variables that are typically used to define the effectiveness and efficiency of the forward skating stride (Lockwood & Frost 2007). The longer the stride (SL) and the fewer number of strides (SF) required to cover a given distance, contributes to a greater effectiveness and efficiency of the forward skating stride. Coordinated relationships between stride length and knee flexion at weight acceptance, trunk angle, and hip and knee extension following toe-off contributed to a longer stride length, meaning that once a more upright forward lean was established a deeper knee bend and coordinated increased extension in the lower limb led to a longer stride length and overall, a more effective stride mechanics. Participants acquired a better understanding of how to coordinate and consistently integrate lower body mechanics into more effective stride mechanics through multiple repetitions of skate treadmill training sessions.

In summary, Block A elicited the greatest amount of improvement in stride mechanics, Block B retained the improvements seen in the initial Block A, and the second Block A revealed minimal changes or a plateau in improvement. The pattern of improvement could potentially be explained using both conceptual and methodological training rationales. Conceptually, the pattern of improvement could be explained by an understanding of the stages of skill development for developmental athletes. The first two stages are initiation and acquisition (CAC, 2020) and occur quickly in developmental athletes. During block A (sessions 1-6), technical development in skating movement patterns was initiated with exposure to skate treadmill training. With repetitive practice and trainer feedback, participants acquired improved movement mechanics and understanding associated with effective stride mechanics.

Alternatively, the methodological training rationale could be explained by a progressive overload theory. In order to further develop skills, the training intervention must provide the appropriate overload progression. The initial Block A included a sufficient overload of training consisting of training volume (s), treadmill incline (°), and treadmill speed (mph). The training intervention in the second Block A was overload using complexity defined as the addition of skating with sticks and pucks. Previous work by Harris (2010) explored using complexity as an overload parameter when developing the skill of skating and found positive physiological and mechanical outcomes. The plateau in improvement as seen in the second Block A could be partially explained by lack of sufficient overload relative to the skating mechanics acquired in the first Block A, and indicates that the addition of complexity did not further elicit ongoing improvements. A low to moderate training intensity was prescribed based on age and ability of athlete. Being that intensity required to elicit mechanical adaptation is not well documented and often a result of trial and error, it is suspected that the intensity prescribed for the second Block A (sessions 7-12) might not have been great enough to elicit further mechanical adaptations.

5.1 Conclusion

Outcomes of the present study have provided support for mechanical adaptation in stride mechanics as a result of minimal exposure to a skate treadmill training intervention. A twelve-session skate treadmill training intervention had a positive effect on the participants' stride mechanics and provides a low-moderate stimulus for change in stride mechanics. The results can inform the scientific and athletic community of the full body movement mechanics of youth ice hockey players on a skate treadmill and on the dose-response relationship between skate treadmill training and stride mechanics adaptations as a result of training in youth ice-hockey players.

The application of the results to forward skating on ice was not directly explored in the current study; however, it is anticipated that the improvements in stride mechanics have the potential to be transferred to the execution of the same skill on ice. During a hockey game, if a player can push longer and use less strides over time, that player will likely arrive at the destination in the game having used less energy over time and thus be able to continue play longer. The more consistent stride mechanics of the athlete's also allows for a more effective stride to be repeatable and less energy to be used more consistently during a hockey game.

5.2 Limitations

Limitations of the study included:

1. The study participants were twenty-three, youth ice hockey players (9.7 ± 0.5 y) who currently play in the positions of forward and defense, and the results of the study are applicable to this group of hockey players only.
2. The duration of the intervention was twelve sessions scheduled over 9 weeks. The design of the study limits what can be known about the effect of training if the training intervention was over a longer period of time or included additional or varied, sessions.
3. Two-dimensional kinematic analysis was limited to left leg data assuming anatomical and biomechanical symmetry between both legs.
4. Kinematic joint angle data were reported to the nearest degree. The two-dimensional marker-less motion capture system used in the current study provides estimates of where the joints of the human body are in space following a recording, but does not possess the same capture power and accuracy that would be achieved with a multi-camera three-dimensional motion capture system and therefore there is less confidence to report data to the nearest decimal point.

References

2013 Canadian Society for Exercise Physiology (CSEP). *Canadian Society for Exercise Physiology. Physical Activity Training for Health (CSEP-PATH)*. Ottawa, ON, Canada: Canadian Society for Exercise Physiology, 2013.

2020 Coaching Association of Canada (CAC). *National Coaching Certification Program (NCCP). Planning a Practice: Reference Material*. Ottawa, ON, Canada: Coaching Association of Canada 2020. Retrieved from http://www.coachesontario.ca/wp-content/uploads/PAPR.pdf

2020 Canadian Society of Exercise Physiology (CSEP). *Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration of Physical Activity, Sedentary Behaviour, and Sleep*. Ottawa, ON, Canada: Canadian Society for Exercise Physiology, 2020. Retrieved from https://csepguidelines.ca/children-and-youth-5-17/

Balsalobre, C. (2020). *My Jump 2* [Mobile App]. App Store. Retrieved from https://apps.apple.com/ca/app/my-jump-2/id1148617550

Balyi, I., Hamilton, A., & Robertson, S. (2005). *Canadian sport for life. [electronic resource]: long-term athlete development: resource paper v.2*. Canadian Sport Centres.

Bosco, C., Luhtanen, P., & Komi, P. (1983). A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology and Occupational Physiology*, *50*(2), 273–282. https://doi.org/10.1007/BF0042216

Bracko, M., & Geithner, C. (2010). A Kinematic Analysis of Skating Speed in Canadian Female University Hockey Players. *Medicine & Science in Sports & Exercise*, *42*, 174.

Burr, J., Jamnik, V., Dogra, S., & Gledhill, N. (2007). Evaluation of Jump Protocols to Assess Leg Power and Predict Hockey Playing Potential. *Journal of Strength and Conditioning Research*, *21*(4), 1139–1145. https://doi.org/10.1519/00124278-200711000-00027

Dreger, R. (1997). Using skate-treadmills to train hockey players for speed. *Strength & Conditioning*, *19*(6), 33–35.

Harris, D. (2010). *The Effect of an Eight Session Skate Treadmill and Agility Training Program on the Degree of Separation in Ice Hockey Players* (Unpublished masters dissertation). Brock University, St.Catharines, Ontario, Canada.

Higgs, C., Balyi, I., Way, R., Cardinal, C., Norris, S., and Bluechardt, M., (2016). Developing Physical Literacy: A guide for parents of children ages 0 to 12. *Sport for Life Society.* Retrieved from http://sportforlife.ca/wp-content/uploads/2016/12/DPL_ENG_Feb29.indd_.pdf

Higgs, C., Balyi, I., Way, R., Cardinal, C., Norris, S., and Bluechardt, M. (2017). LTAD - Sport for Life. *Sport for Life Society.* Retrieved from http://sportforlife.ca/wp-content/uploads/2017/04/LTAD-2.1-EN_web.pdf?x96000

Higgs, C., Way, R., Harber, V., Jurbala, P., Balyi, I., Carey, A., Trono, C., Mitchell, D., Grove, J., & Laing, T. (2019). 3.0 LONG-TERM DEVELOPMENT IN SPORT AND PHYSICAL ACTIVITY. *Sport for Life Society*, 48.

Hockey Canada (2013). Hockey Canada Long Term Player Development Plan Hockey For Life, Hockey For Excellence. Retrieved from http://www.hockeyeasternontario.ca/docs/HC_LTPD_Manual.pdf

Jackson, J., Snydmiller, G., Game, A., Gervais, P., & Bell G. (2016). Movement Characteristics and Heart Rate Profiles Displayed by Female University Ice Hockey Players. *International Journal of Kinesiology and Sports Science*, (1), 43.

Lepine, J., & Frappier, J. (1995). *U.S. Patent No. 5,385,520*. Washington, DC: U.S. Patent and Trademark Office.

Lockwood, K., & Frost, G. (2007). Habituation of 10-year-old hockey players to treadmill skating. *Sports Biomechanics*, *6*(2), 145–154.

Lockwood, K., & Jackson, G. (2010). Infrastructure & Expertise: A Model to Investigate Effective Training through Long-term Athlete Development. *Sport Canada Research Initiative Conference.* Retrieved from https://sirc.ca/sites/default/files/content/docs/Document/klockwood_kt_en.pdf

Marino, G. (1974). A COMPARATIVE ANALYSIS OF SELECTED MECHANICAL ASPECTS OF THE ICE SKATING STRIDE.

McPherson, M., Wrigley, A., and Montelpare, W. (2004). The biomechanical characteristics of development age hockey players: Determining the effects of body size on the assessment of skating technique. In D. J. Pearsall, and A. B. Ashare (Eds.), *Safety in ice hockey*, Fourth Volume (pp. 272–287). West Conshohocken: ASTM International.

Montgomery, D., Nobes, K., Pearsall, D., & Turcotte, R. (2004). Task analysis (hitting, shooting, passing and skating) of professional hockey players. *Safety in Ice Hockey*: Fourth Volume, ASTM STP 1446, D. J Pearsall and A. B. Ashare (Eds.) ASTM International. p.288-295.

Nobes, K., Montgomery, D., Pearsall, D., Turcotte, R., Lefebvre, R., & Whittom, F. (2003). A Comparison of Skating Economy On-Ice and On the Skating Treadmill. *Canadian Journal of Applied Physiology*, *28*(1), 1–11.

Pearsall, D., Turcotte, R., Lefebvre, R., Bateni, H., Nicolaou, M., Montgomery, D., and Chang, R. (2001). Kinematics of the foot and ankle in forward ice hockey skating. *XIX International Symposium on Biomechanics In Sports*, ISBS.

Pearsall, D., Turcotte, R., Murphy, S.D. (2000). Biomechanics of ice hockey. *Exercise and Sport Science*. 675-692.

Python™ (2019). *Python Software Foundation* (version 3.7). Wilmington, Delaware, United States.

Practice. (2019). In *Merriam-Webster Dictionary online.* Retrieved from https://www.merriam-webster.com/dictionary/practice

Renaud, P., Robbins, S., Dixon, P., Shell, J., Turcotte, R., & Pearsall, D. (2017). Ice hockey skate starts: a comparison of high and low calibre skaters. *Sports Engineering*, (4), 255.

Renger, R. (1994). Identifying the Task Requirements Essential to the Success of a Professional Ice Hockey Player: A Scout's Perspective. *Journal of Teaching in Physical Education*, *13*(2), 180–195.

Schweigert, D., & Frappier, J. (2002). Treadmill running to improve speed. *Strength & Conditioning Journal*, *24*(3), 27–29.

Shell, J., Robbins, S., Dixon, P., Renaud, P., Turcotte, R., Wu, T., & Pearsall, D. (2017). Skating start propulsion: three-dimensional kinematic analysis of elite male and female ice hockey players. *Sports Biomechanics*, *16*(3), 313–324.

Statistical Package for the Social Sciences (SPSS) statistical software (2019). *SPSS for Windows* (version 26). Chicago, Illinois, USA.

Stidwill, T., Pearsall, D., & Turcotte, R. (2010). Comparison of skating kinetics and kinematics on ice and on a synthetic surface. *Sports Biomechanics*, *9*(1), 57–64.

Swanson, S. (n.d.). Why it Works: The Science Behind Treadmill Training. *Athletic Republic.*

Tidman, R., (2015). *Hockey Skating Kinematics and the Effect of Skate Design and Technique Training.* (Unpublished masters dissertation). Marquette University, Milwaukee, Wisconsin, USA.

Trempe, M., & Proteau, L. (2012). 11 Motor skill consolidation. Skill Acquisition in Sport: *Research, Theory and Practice,* 192-203.

Trempe, M., Sabourin, M., Rohbanfard, H., & Proteau, L. (2011). Observation learning versus physical practice leads to different consolidation outcomes in a movement timing task. *Experimental Brain Research, 209*(2), 181-192.

Upjohn, T., Turcotte, R., Pearsall, D., & Loh, J. (2008). Three-dimensional kinematics of the lower limbs during forward ice hockey skating. *Sports Biomechanics, 7*(2), 206–221.

Wrnch.ai (2020). *wrnchAI* (Version 1.17.0). Wrnch.ai, Montreal, QC.

Appendix A - Player Demographic and Equipment Questionnaire

Participant Information:

To be completed by participant:

Name: ____

Date of Birth (DD/MM/YYYY):_____________________________

Years of Hockey Experience: ________________________________

Level (i.e. A, AA, AAA):_______________________________

Primary Hockey Position (circle one): Forward Defense

Will you be playing any other sports during the course of this study? If yes, list sports:

____

Years of Experience playing other sports:

____

____

Level played in other sports (i.e., A, AA, AAA, BB, B, House league):

____

Equipment Information:

Skate Brand (E.g. Bauer, CCM, etc.):_______________________________________

Holder Brand (Example: Tuuk):____

Blade Brand (Example: Tuuk LS3 or LS4):__________________________________

To be completed by evaluator:

Height (cm): __________________ Weight (kg):_____________

Sitting Height (cm):________________ Vertical Jump Height (cm):____________

Appendix B – Activity Journal

Activity Journal Example

Please record on this sheet, practices/games for sport participation other than hockey. For example, if you have soccer practice or a volleyball game please record the day, sport, time and intensity of the **game.**

Date (DD/MM/YYYY)	**Activity/Sport (Eg., Soccer, Volleyball)**	**Time (hours & min) (E.g., 1 hour)**	**Intensity (high, moderate, low)**

Intensity: **High** = Games and practices that are you are exhausted after or pretty tired, where you were sprinting or playing as hard as you could for most of the activity. **Moderate** = Jogging or playing but not as hard as high intensity. **Low** = Not very much effort needed, light jog or walk.

Appendix C – Power Analysis

Power analysis Protocol Using G-Power

F tests – ANOVA: Repeated measures, within factors

Analysis:	A priori: Compute required sample size		
Input:	Effect size f	=	0.25
	α err prob	=	0.05
	Power (1−β err prob)	=	0.8
	Number of groups	=	1
	Number of measurements	=	7
	Corr among rep measures	=	0.5
	Nonsphericity correction ϵ	=	1
Output:	Noncentrality parameter λ	=	14.8750000
	Critical F	=	2.1945162
	Numerator df	=	6.0000000
	Denominator df	=	96.0000000
	Total sample size	=	17
	Actual power	=	0.8106070

Appendix D - Letter of Invitation

The Effect of a Skate Treadmill Training Intervention on Stride Mechanics

Kelly Lockwood, PhD
Associate Professor
Department of Kinesiology
Brock University
905-688-5550 ext. 3092
klockwood@brocku.ca

Dylan Lamers
MSc Candidate
Department of Kinesiology
Brock University

dl13ym@brock.ca

Invitation
You are invited to participate in a Master's thesis research project examining the effect of a twelve-session training intervention on stride mechanics in Atom aged (9-10 years old), male, competitive ice hockey players.

What's Involved
As a participant, you will be asked to complete a 9 week, twelve-session training intervention, divided into three, 3-week blocks. Each session will be 1-hour in duration. The first session will be a familiarization session scheduled prior to Block 1 and include a pre^1 vertical jump assessment. Block 1 will include a post^1 vertical jump assessment and six, 1-hour skate treadmill training sessions. Block 2 will mimic the duration of Block 1 and include no skate treadmill training. Block 3 will include pre^2-post^2 vertical jump assessments and six, 1-hour skate treadmill training sessions. All sessions will be scheduled in small groups (max of 6 athletes), with 24-48 hours between sessions, and scheduled to compliment team related on-ice practices, games and tournaments. A 1-hour familiarization session will be used to introduce the participants to the researchers and the lab. Participants will be required to complete a total of thirteen 1-hour sessions. The total time commitment for the study is 13 hours over nine weeks. Only players who have no previous treadmill experience, are self-reported as injury free, currently play the position of forward or defense, and are willing to have photos/videos taken and used in the dissemination of results are eligible to participate. Participants will be restricted from any other hockey related training programs except team related on-ice practices/games to help limit the effect of other training stimuli on study outcomes. Participants will not be restricted from playing other sports during the study due to the notion that other sports will not necessarily be working on stride mechanics that would resemble skating mechanics and will not affect the outcome of the study. Participants will be required to complete a log of all physical activity and sport participation outside of the study in a journal to confirm the activity levels of the participants in terms of practices and games.
Details of the training sessions and assessments are as follows:
Training: All training sessions will be instructed by the student researcher in the On Ice Performance Laboratory at the Brock University. The address is as follows: 1812 Sir Isaac Brock Way, On-Ice Performance Lab (WC 100), St. Catharines, Ontario. All training sessions will be 1-hour in duration consisting of a standardized warm-up of 500 skips and 45 minutes of skate treadmill training.

- Participants will complete a standardized warmup of 500 skips. Participants will wear their own skates, sharpened for game like conditions. Participants will be fit with a climbing-like harness, and then secured to an overhead safety gantry. A second warmup will be conducted on the treadmill consisting of three, 20 second intervals of forward treadmill skating.
- The skate treadmill training protocol will consist of speeds and inclines that are age and ability appropriate. Training will consist of 10-12 forward skating drills, each lasting 5-30 s. One participant will be on the skate treadmill at any given time allowing for training sessions to maintain a work: rest ratio of 1:5.

Familiarization session, Pre-Post Vertical Jump Assessments, and Skating Mechanics Assessments:

1. A 1-hour familiarization session will be scheduled prior to Block one of training to introduce the participants to the researchers and the lab. Participant assent and parental consent forms, player demographics and equipment questionnaire will be emailed to the parents to be completed in the privacy of their own home and returned via email or collected by the researchers at the familiarization session. Anthropometrics measures including: height (cm), sitting height (cm), and weight (kg) will be collected. Vertical jump height (m) will be collected and participants will be familiarized on a skate treadmill during this session.
2. Vertical jump height assessments will be conducted during familiarization, post Block 1 and pre-post Block 3. Participants will be video-recorded while performing a counter-movement vertical jump in order to assess leg power. Participants will be video recorded while performing a vertical jump. Participants will perform 1 practice jump and 3 trials of the vertical jump protocol with 40 s of rest between trails.
3. Skating mechanics assessments will be conducted at the end of all training sessions:

Assessments will be on the treadmill; participants will then be video recorded while skating on a treadmill elevation (degrees) and speed (mph) defined during the familiarization session to be an appropriate skating incline and speed with respect to age and ability of the participant cohort, for ten consecutive strides. Should the participant stumble, trip or fall, the participant will be provided with adequate rest and asked to repeat the 10-stride interval.

Potential Benefits and Risks

Potential benefits of participation include the opportunity to complete a sport-specific training intervention, using a simulated device that has the potential to improve skating mechanics. This study also has the potential to benefit the scientific and athletic community by adding to knowledge regarding effective training practices with respect to skating mechanics on a skate treadmill, the effect of skate treadmill training and specifically a dose-response relationship for mechanical training for youth, as well as the retention of mechanical adaptions following training. Dose is defined for the purpose of the training study as exposures in minutes to skate treadmill training. Each session is one hour in duration and the time each athlete is on the treadmill will be recorded. The response is the adaptation or mechanical response to training. During all assessments and training sessions, participants may experience risks associated with physical exertion and/or physical stress. Although, it is not possible to predict all possible risks or discomforts that a participant may experience during a research study involving human activity, the intensity of the activities as outlined by the study protocol are considered to be less strenuous than a practice or game of ice hockey. Training will focus on skating mechanics as opposed to physiological development or fitness effects. Although, it is recognized that there may be some fatigue related to skating intermittently for one hour. Training will be conducted in small groups of 6 skaters. Within each group the participants can make their own observations, however kinematic variables such as stride length and stride frequency are difficult for 9-10 year old participants to assess subjectively. So, it is unlikely that the participants will be able to make judgement on how well the skater is doing. Participants will perform vertical jumps in a separate room from other participants in order to avoid participants observing how another participant performs on the vertical jump assessment.

Participants will receive verbal and written statements detailing their right to decline or withdraw from the study at any time. Should the participant wish to withdraw from the study, they may do so by verbally informing the principal investigator or student investigator, without any penalty. Upon withdrawal from the study, participant data will be destroyed by deleting any electronic data or video file related to their participation.

Confidentiality

All information you provide is considered confidential. All participant data, including names height, weight, birthdate, questionnaire data detailing hockey experience and video files will be individually coded. So, although participants names will be associated during data collection, data will be deidentified and only coded data will be analyzed. The electronic data will be stored on a research dedicated external hard drive that is password protected and retained by the principal researcher. All hard copies of data (e.g., physical activity journals, player demographics, equipment questionnaire, informed assent and parental consent forms) will be stored and locked in a research dedicated cabinet. Personal identifiers (participant names and email addresses) will be retained in a master list so that participants can be provided with a feedback letter and group results following the completion of the study. Participants will be provided with a pre-post summary of training results. The results will include the mean group kinematic measures. During all assessments, the data cannot be anonymous, as the researcher will be conducting physical measurements and recording video of the participants skating on the treadmill and performing vertical jumps. That said, all participants data collected during assessments will be coded through the use of ID numbers to facilitate confidentiality of electronic records and eliminate the use of personal identifiers. Video recordings will be saved, coded, downloaded to an external hard-drive, and linked to the same personal ID number assigned to the participants physical data. Initial physical and video collection of data cannot be anonymous, however once the physical data is coded and video recordings are analyzed by three dimensional coordinates or vertical jump height (no images), the data used for the purpose of analysis will facilitate confidentiality. If video recordings or photos are used in dissemination of results, faces will be covered/blocked in order to facilitate confidentiality. Hard copies and electronic copies of all data (videos included) will be retained for a period of five years following the completion of the study, approximately June 2020. After a period of 5 years hard copies and electronic copies of data will be deleted and/or destroyed. Access to this data will be restricted to Dr. Kelly Lockwood and Dylan Lamers.

Participation

Participation in the research requires attendance at all training sessions. However, provisions have been established if an athlete should miss a training session. A make-up session will be scheduled during the same week. If a participant misses a training session and are unable to reschedule the participant will be removed from the study and will not receive further training or group results. All training sessions will be under the supervision of the student principal investigator, MSc. candidate Dylan Lamers and/or Dr. Kelly Lockwood. You may withdraw your participation from the study at any time. There are no consequences of withdrawing from the study. If the participant chooses to withdraw, their data will be destroyed by deleting any file(s) related to their participation, at any point during the study. Participants will not be provided group feedback if they choose to withdraw, do not attend all sessions or make-up sessions, and if permission for photos/videos to be used in dissemination of results is not provided.

Publication of Results

A summary of the results of study will be distributed to all participants approximately June 2020, following the completion of the master student's defense that is associated with the project. Furthermore, scientific results of this study may be published in academic or practitioners' journals and/or presented at scientific conferences to advance our knowledge of the effect of skate treadmill training on stride mechanics in competitive, male, ice hockey players. Only age and playing positions of the participants will be utilized as possible identifiers in the analysis and publication of results.

Contact Information and Ethics Clearance

If you have any questions about this study or require further information, please contact Dr. Kelly Lockwood or Dylan Lamers using the contact information provided above. This study has been reviewed and received ethics clearance through the Research Ethics Board at Brock University [File# 19-037]. If you have any comments or concerns about your rights as a research participant, please contact the Research Ethics Office at (905) 688-5550 Ext. 3035, reb@brocku.ca .

If you are interested in participating please complete the attached Informed Assent and Parental Consent form, player demographics and equipment questionnaire, and submit it to Dr. Kelly Lockwood or Dylan Lamers at the scheduled familiarization session. Please keep a copy of this form for your records. Thank you for your assistance in this project.

Dylan Lamers and Dr. Kelly Lockwood

Appendix E – Informed Assent and Parental Consent Form

I agree to participate in the study as described above. I have made this decision based on the information provided through reading this document and assent that:

- I have had the opportunity to receive any additional details.
- Although we have strict policies in place to protect all participants in the program, accidents do happen. I understand that the instructors are qualified and will act in the best interest of the athletes.
- I understand that I may ask questions at any time with regard to the study.
- I understand that I may withdraw this consent at any time during the study.
- I understand that assessments will take place in groups with other participants viewing my performance. There may be a loss of privacy, since training and assessments will be conducted in small groups of 6 skaters. Within each group the participants can make their own observations, however kinematic variables such as stride length and stride frequency are difficult for 9-10 year old participants to assess subjectively. So, it is unlikely that the participants will be able to make judgement on how well the skater is doing. However, only the researchers will see my results.
- Participant's names and data remain confidential by coding each participant individually by number.
- Participants will receive a copy of the Informed Assent and Parental Consent Form and a summary of the research project upon completion.
- I have read and understand the information in the letter of invitation.

For Participants and Guardians to complete:

Participant Assent:

In signing this form, I ____ (Participant's Name) and __________________________________ (Guardian's Name) acknowledge that I have received an explanation about the nature of the study and its purpose.

Parental/Guardian Consent:

I ____(Guardian's Name) give my permission for ____________________________ (Participant's Name) to participate in the research as described above conducted by Dr. Kelly Lockwood and Dylan Lamers.

Photo Permission:

In signing this form, I ___________________________________(Guardian's Name) give permission for photos and videos of ____________________________ (Participant's Name) to be used by Dr. Kelly Lockwood in presentations of the research (E.g. poster presentation at a conference).

(NOTE: Photo permission is required to participate.)

Participant's Name: ____

Participant's Signature: ____

Guardian's Name: ____

Guardian's Signature: ____

Date: ____

Appendix F – Participant Feedback Letter

The Effect of a Skate Treadmill Training Intervention on Stride Mechanics

Kelly Lockwood, PhD
Associate Professor
905 688 5550 x 3092
klockwood@brocku.ca

Dylan Lamers, BKin
MSc Candidate
dl13ym@brocku.ca

Dear participant,

Thank you for participating in the project entitled "The Effect of a Skate Treadmill Training Intervention on Stride Mechanics." The purpose of this study was to investigate the effect of a twelve-session training intervention on stride mechanics in youth (9.7 ± 0.05 y), competitive ice hockey players.

Twenty-three youth ice hockey players (9.7 ± 0.05 y) participated in the study. Outcomes of the study revealed a 1.9% increase in stride length (mm) and 5.0% decrease in stride frequency (Hz), a 6.4% decrease in trunk angle at weight acceptance (°) and 5.4% decrease in trunk angle following toe-off (°), a 1.7% increase in hip flexion and 4.3 % in knee flexion at weight acceptance (°), a 5.9% increase in hip extension and 7.5% increase in knee extension following toe-off (°) following a twelve session (9-week) training intervention. Summary of study results will be distributed with the feedback letter.

Should you have any further questions with regard to the purpose or results of the study, please feel free to contact either Dylan Lamers or Kelly Lockwood using the contact information provided above.

Thank you for your assistance in this project and best of luck in the rest of the hockey season.

Dylan Lamers and Kelly Lockwood