

Women's Ice Hockey

A Review of Literature

Katie Schwab, CSCS

April 2014

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Ice hockey can arguably be considered one of the most physically difficult sports. Pete Broccoletti (1986) describes ice hockey as: “There’s no other sport that demands so much. It requires the ability and agility of a figure skater, and the quickness of a speed skater. Physically, it demands the power of a football player to dig in the corners for the puck and absorb full-speed collisions while checking an opponent. Then comes the ability to handle and control a puck, a skill more difficult than finessing a golf ball across a slick green into the cup.” Montgomery (1988) notes that the length of the game and the player substitutions (referred to as shifts) contribute to the physical difficulty. At the elite level, an ice hockey game consists of three, twenty minute periods of play with a fifteen-minute minute break in between periods. During periods, the clock is only running when the puck is in play. Game play is characterized by intermittent high intensity skating that varies in velocity, direction, and duration (Montgomery, 1988). In order to successfully compete at a collegiate level, athletes must be able to meet the high demands hockey places on both the oxidative and glycolytic energy systems. Athletes must also have the strength, power, and flexibility to meet the agility and technical skill required to skate, shoot, and pass the puck (Twist & Rhodes, 1993).

The intensity of ice hockey demands a superior off-ice training program. In order to reach this level of conditioning, a strength coach must have knowledge of the ideal movement patterns, physiological requirements, and common injuries associated with ice hockey. This literature review will address the above aspects with a specific focus on women’s ice hockey. The primary difference between men’s and women’s hockey is the absence of body checking in women’s hockey. Although women’s ice hockey has grown in popularity since 1998, when it first became a medal sport in the Olympic Winter games, the majority of ice hockey research available is from studying men’s hockey (Bracko, 2001; Geithner, Lee, & Bracko, 2006). Limited data is available on the physical and performance characteristics of women’s hockey; therefore, this literature will use the available research on women’s hockey and supplement with research on men’s hockey when it is necessary. This literature review will further include information on common methods used to test physiological capacities and provide established injury prevention methods. However, this literature review will not cover the additional physical demands imposed by body checking, nor the psychological demands and the different challenges presented by the external environment, including ice surface and arena quality.

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Movement Patterns for Ideal Performance

Successful women hockey players must be familiar with the general movement patterns of skating and stick handling. Skating has been identified as the most important skill; therefore, this section will focus primarily on the ideal movement patterns of skating (Bracko, 2001; Bracko, 2004; Upjohn, Turcotte, Pearsall, & Loh, 2008; Pearsall, Turcotte, & Murphy, 2000). Skating, however, consists of a wide variety of movement patterns. Bracko, Hall, Fischer, Fellingham, & Cryer (1998), in their analysis of the performance skating characteristics of National Hockey League (NHL) forwards, found that 39% of ice time during a shift was spent gliding on two feet. The next most common skating positions of NHL forwards—by percentage of total time on ice—are as follows: cruise slide (16.2%), medium intensity skating (10%), struggle for puck or position (9.8%), low-intensity skating (7.8%), backward skating (4.9%), and high-intensity skating (4.6%) (Bracko, 2004). Manners' (2004) analysis of ice hockey simplifies the skating strides into three categories: the forward skating stride, the backward skating stride, and the crossover. However, all skating characteristics originate from the two-foot gliding position; therefore, the forward glide is one of the fundamental movement patterns and the one this literature review will focus on (Bracko et al., 1998; Bracko, 2004; Manners, 2004; Upjohn et al., 2008).

Skating is a unique form of locomotion for humans because the reactive push-off force cannot be initiated in the backward direction, which is done in common locomotion such as walking and running (Pearsall, Turcotte, & Murphy, 2000; Bracko, 2004). This inability to utilize a backward push-off is due to the low coefficient of friction between the skate blade and the ice; therefore, the direction of the push-off must be perpendicular to the gliding direction of the skate (Pearsall et al., 2000; Moeller & Bracko, 2004; Bracko, 2004). This prevents the hip joint from moving through normal flexion and extension, and instead requires the hip joint to abduct and externally rotate in order to achieve this lateral push-off. This causes substantial movement in both the sagittal and frontal planes, and creates a wave-like trajectory throughout the forward skating motion (Moeller & Bracko, 2004; Bracko, 2004; Upjohn et al., 2008). Some coaches tell their players to practice flexion and extension of the shoulders and hips—normal for forward locomotion such as walking and running—while skating (Bracko, 2004). This is actually counterproductive and in fact almost impossible to do while skating; the hips are forced to abduct and adduct to achieve the lateral push-off required. The shoulders will automatically

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abduct and adduct with the hips because of Newton's third law of action-reaction (Bracko, 2004). The action of abduction and adduction in the hips dictates that the glenohumeral joint must have a reaction of abduction and adduction in order to complement the sinusoidal skating pattern and maintain balance, momentum, and forward velocity (Moeller & Bracko, 2004; Bracko, 2004).

Pearsall et al. (2000) and Upjohn et al. (2008) refer to the skating stride as biphasic, consisting of the support and swing phases. The support phase can then be further divided into single- and double-support phases. Marino & Weese (1979) and Moeller & Bracko (2004) have classified skating as triphasic, composed of the single-support propulsion phase, double-support propulsion phase, and single-support glide/recovery phase. This review will examine the biomechanics of forward skating using the triphasic classification.

In the forward skating stride, the single-support propulsion phase starts about halfway through the single-support glide/recovery phase, continues through the entire double-support phase, and ends at the end of the double-support phase when the propulsion skate becomes the recovery skate (Marino & Weese, 1979; Moeller & Bracko, 2004; Pearsall et al., 2000). Approximately 18% of the support phase is spent in single-support and 82% is spent in the double-support phase (Marino, 1983). The single-support recovery phase is the time immediately after the propulsive skate pushes off and before it is brought forward and returned to the ice (Marino & Weese, 1979). This brief phase is also referred to as the single-support glide phase because one skate is gliding and the skater is briefly decelerating (Marino & Weese, 1979). The double-support phase starts when the recovery skate is put back on the ice (Marino & Weese, 1979; Moeller & Bracko, 2004). In the double-leg propulsion, the player has their skates slightly wider than shoulder width apart, knees and trunk flexed, and ankles dorsiflexed (Bracko, 2004). The hips are flexed to approximately 30° degrees and the knees to 50° (Manners, 2004). This position places the center of gravity outside of the base of support, indicating that balance and the ability to maintain this position are highly important for game-performance (Bracko, 2004).

Forward propulsion is derived from summing hyperextension and abduction of the hip, extension of the knee, and plantar flexion of the ankle (Pearsall et al., 2000). However, due to the design of the hockey skate, the ankle has a limited range of motion, indicating that propulsion is derived primarily from knee extension and hip abduction and extension (Pearsall et al., 2000; Moeller & Bracko, 2004). Therefore, the primary leg muscles involved in propulsion are: the

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quadriceps, the hip abductors, and the gluteus maximus, with the gluteus maximus being primarily responsible for the majority of the power production during push-off (Pearsall et al., 2000; Moeller & Bracko, 2004). The quadriceps muscles are most active when extending the knee during the propulsion phase and the hamstring muscles are most involved during the gliding phase (Pearsall et al., 2000; Moeller & Bracko, 2004).

These skating characteristics ensure proper and effective forward skating, yet there are certain factors that differentiate fast skaters from slower skaters. These characteristics include: increased left and right stride width, greater width between strides, and greater hip abduction angle (Moeller & Bracko, 2004; Bracko, 2004). Additionally, skating speed increases with stride frequency and is negatively related to stride length (Moeller & Bracko, 2004; Pearsall et al., 2000). Fast skaters can improve their stride rate by: keeping the recovery foot close to the ice while bringing it forward, having quicker knee extension during propulsion, maintaining greater knee flexion prior to push-off, and keeping a greater forward lean of the trunk (Bracko, 2004; Moeller & Bracko, 2004; Marino & Weese, 1979). Higher-caliber skaters also generate more power, which increases skating speed (Upjohn et al., 2008).

Skating is the most important skill in hockey; therefore, proper skating mechanics are essential to performance. Once the basics of the skating stride are mastered, players can make small changes to improve skating speed.

Physiological Requirements

Ice hockey is a physiologically demanding sport. It is an intermittent game consisting of fast, explosive movements, interspersed with sub-maximal skating and rest periods (Twist & Rhodes, 1993a; Twist & Rhodes, 1993b). In addition to having a well-developed ATP-CP and lactic acid systems to sustain repeated near-maximal sprints, hockey players must also have a good aerobic base to facilitate rapid recovery (Twist & Rhodes, 1993a; Twist & Rhodes, 1993b). A strength coach must have a good understanding of the intermittent nature of hockey to be able to properly train and develop the energy systems to achieve maximal performance.

Energy System Requirements

Aerobic Energy System

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There is some debate about the effectiveness of the aerobic energy system in facilitating rapid recovery during repeated, high-intensity sprints. In their literature review, Tomlin and Wenger (2001) concluded that having an aerobic base will help recovery from intermittent sprints by increasing the aerobic response, aiding rapid lactate removal and improving PCr re-synthesis. Twist & Rhodes (1993a) also mention that adjacent, well-conditioned slow twitch muscle fibers can contribute to lactate clearing and reoxidation, even if the fibers were not used during skating. However, Carey, Drake, Pliego, & Raymond (2007) found that in Division III female college hockey players, aerobic capacity, as measured by VO_{2max} , was not indicative of significantly faster recovery after high-intensity exercise. Carey et al. (2007) suggest that there is a minimum level of aerobic fitness needed to enhance recovery, and anything above that level provides no additional recovery benefits.

Despite the controversy over the amount that the oxidative energy system may speed up the recovery process, it is known that having an efficient oxidative system is necessary for recovery and is an important aspect of ice hockey training (Moeller & Bracko, 2004; Twist, 2007; Twist & Rhodes, 1993a; Twist & Rhodes, 1993b; Carey et al., 2007). The aerobic energy system supplies the energy demands for the players between shifts and between periods (Moeller & Bracko, 2004). In fact, it has been estimated that 31% of the energy requirements for ice hockey are supplied by the oxidative energy system (Moeller & Bracko, 2004). A well-developed aerobic base will enhance endurance, which is important in hockey because shifts are repeated over 60 minutes of game play (Twist, 2007; Bracko, 2001). In addition to improving endurance, the aerobic system will enable players to utilize oxygen as fuel at higher intensities for a longer duration before relying on anaerobic mechanisms, such as the ATP-CP or glycolytic systems (Twist, 2007). Furthermore, the resynthesis of the ATP-CP system relies on the oxidative energy system (Moeller & Bracko, 2004).

The recovery effects of the oxidative system are particularly important for forwards, who spend more time working anaerobically (Twist & Rhodes, 1993b). For defensive players, the endurance aspect is beneficial (Twist & Rhodes, 1993a). Defensive players typically spend more time on the ice (50 percent of the game compared to 35 percent for forwards), skate slower than forwards, have shorter off-ice recovery periods, and higher off-ice heart rates (Twist & Rhodes, 1993a; Twist & Rhodes, 1993b); Geithner et al., 2006). Increased time on the ice and slower

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speeds indicate that defensive players will utilize their oxidative energy system more during the game compared to forwards (Twist & Rhodes, 1993a).

Twist & Rhodes (1993a) found that elite hockey players have an optimal VO_2 of about 60 ml/kg/min for forwards and above 50 ml/kg/min for defensive players and goalies. The University of Alberta's women's hockey team had an average predicted $\text{VO}_{2\text{max}}$ of 45.9 ml/kg/min, 43.3 ml/kg/min, and 41.1 ml/kg/min for forwards, defensive players, and goalies, respectively (Geithner et al., 2006). In Division III female hockey players at St. Thomas University, Carey et al. (2007) reported an average $\text{VO}_{2\text{max}}$ of 50.3 ml/kg/min.

Anaerobic Energy System

While the aerobic system is important, it is not the primary fuel supply for ice hockey (Twist, 2007). Barnes and Fry (n.d.) state that hockey is a predominately anaerobic sport. In fact, about 69% of the energy demands in ice hockey are supplied by a combination of the anaerobic glycolysis and the ATP-CP systems (Moeller & Bracko, 2004). Anaerobic activities include: sprinting, quickness, speed, strength, and power (Twist, 2007).

The ATP-CP system provides immediate fuel for short, maximum-intensity exercises such as explosive starting and shooting the puck (Moeller & Bracko, 2004; Twist, 2007). The glycolytic system peaks after 30 to 45 seconds, but can provide energy for up to 120 seconds (Twist, 2007; Twist & Rhodes, 1993a). Most hockey shifts last an average of 45 seconds, so the primary energy supply on ice is the anaerobic system (Twist, 2007; Twist & Rhodes, 1993a). Stopping, starting, sprinting, and battling for the puck all draw on the anaerobic system (Twist, 2007).

If a player—particularly a forward—has a shift that is longer than 45 seconds, intensity will start to decline as lactate/ H^+ ions begin to accumulate (Twist, 2007; Twist & Rhodes, 1993b). H^+ ion accumulation limits performance by increasing leg stiffness and slowing leg movements (Twist, 2007). Therefore, having a high lactate threshold is beneficial. Nightingale, Miller, & Turner (2013) reported that lactate threshold occurs at 86% of $\text{VO}_{2\text{max}}$ on-ice. Cox, Miles, Verde, & Rhodes (1995) found that lactate threshold occurred between 73 to 92% of $\text{VO}_{2\text{max}}$. Twist & Rhodes (1993b) reported that on-ice oxygen uptake averages 90% of $\text{VO}_{2\text{max}}$, indicating that most of a hockey players' shift is spent at levels above lactate threshold. Thus,

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increasing VO_{2max} and lactate threshold will improve high-intensity sprint duration.

Strength

Absolute strength (total muscular strength) and relative strength (strength in relation to body weight) are both important in hockey (Twist, 2007; Twist & Rhodes, 1993a). Absolute strength provides the mass and strength needed to move others and withstand contact, while relative strength cultivates quickness, speed, and agility (Twist, 2007; Twist & Rhodes, 1993a). Upper body strength is needed to accurately handle and shoot the puck and maintain position (Moeller & Bracko, 2004). Hockey requires considerable leg strength—particularly eccentric strength—in order to stop instantly, rapidly change directions, and negotiate high-speed turns (Twist, 2007). In order to minimize the risk of injury to the hamstrings, hockey players should maintain a hamstring/quadriceps ratio of 60 percent (Twist & Rhodes, 1993a). Core strength is also a key component of hockey. Core strength contributes to: balance during movement, control of tight turns, stabilization during skating and shooting, and transfer of power from the legs to the arms (Twist, 2007).

Muscle hypertrophy is not the primary focus of off-ice training, but having enough lean body mass is important for all aspects of ice hockey. Muscle mass is important for reducing the risk of injury. Muscle mass also provides protection for bones and joints, and improves joint stability (Twist & Rhodes, 1993a). Therefore, it is appropriate to spend some time in the off-season focusing on increasing muscle mass (Moeller & Bracko, 2004). However, too much muscle mass can also be detrimental to skating speed and agility. Newton's Second Law of Motion ($Force = Mass * Acceleration$) states that an increase in body mass will require increased force to produce the same acceleration (Bompa & Haff, 2009). Similarly, more mass will increase momentum, which will require more energy to stop and change directions.

Most strength and conditioning coaches overlook the importance of muscle endurance for ice hockey (Moeller & Bracko, 2004). Muscle endurance should be an aspect of training because the work shifts in hockey are repeated every 4-5 minutes in a period and 12-15 times per game. Some seasons can encompass over 100 games, including preseason and play-offs (Moeller & Bracko, 2004). Skating also requires players to maintain a bent knee, flexed trunk position for the entire game duration. Spending a phase improving muscular endurance is beneficial because it will aid performance.

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Power

While muscular strength is important, muscular power is a necessity for hockey players (Moeller & Bracko, 2004; Barnes & Fry, n.d.; Twist & Rhodes, 1993a). Power is considered one of the primary factors in determining sports performance for most sports (Stone, Stone, & Sands, 2007; Bompa & Haff, 2009; Twist & Rhodes, 1993a; Zatsiorsky & Kraemer, 2006). Different sports require different types of power, ranging from maximal power output during a single-effort event to average power output which is measured in runners and cross-country skiers (Bompa & Haff, 2009). Ice hockey falls in-between this spectrum because it requires continuous bursts of high power outputs throughout an entire game (Montgomery, 1988). Players must be able to react to situations and explode into action repeatedly for the 60 minutes of on-ice playing time (Twist & Rhodes, 1993a; Barnes & Fry, n.d.). This type of power is often referred to as power endurance, or high intensity exercise endurance (Bompa & Haff, 2009; Stone et al., 2006). Power is also an important component of acceleration (Bompa & Haff, 2009). The ability to rapidly accelerate is of primary importance in hockey because players rarely reach maximum speed (Twist & Rhodes, 1993a). Additionally, power improves shooting, struggling for position, and maintenance of high-intensity skating (Moeller & Bracko, 2004; Twist & Rhodes, 1993a).

Flexibility

Flexibility in hockey is important because of the unpredictable movements due to the reactive nature of the sport (Twist, 2007). Joints should be able to easily move through all possible motions to decrease risk of injury (Twist, 2007). Increased flexibility, especially in the hips, groin, and quadriceps, will improve skating speed and efficiency and decrease the risk of injury (Moeller & Bracko, 2004; Twist & Rhodes, 1993a). The bent-leg position of skating indicates that the hamstring muscles are rarely fully stretched. Hamstring flexibility is particularly important because excessive tightness can hinder skating speed and power (Twist & Rhodes, 1993a). If a player is unable to fully extend their rear leg during skating, this both decreases skating speed and leads to poor skating mechanics, resulting in further loss of flexibility (Twist & Rhodes, 1993a). This cycle can be broken by incorporating regular stretching into training. Flexibility training should target not only the hamstrings, but also the hips, groin, quadriceps, and lumbar regions (Twist & Rhodes, 1993a).

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Body Composition

Hockey players tend to be mesomorphic in structure, but body characteristics vary by position (Twist & Rhodes, 1993b; Geithner et al., 2006). In female ice hockey players, forwards are typically the leanest, while goaltenders have the higher body fat percentages (Geithner et al., 2006). Forwards and defensive players tend to be more physically similar, but defensive players have broader hips and greater relaxed arm circumference (Geithner et al., 2006). Positional differences in body composition and structure are due to the demands of the position; the more the position requires speed, agility, ice coverage, aerobic and anaerobic power, the lower the body weight and fat percentage of the players (Geithner et al., 2006). Knowledge of a players' body composition may help coaches place players in specific positions with a greater likelihood of success (Geithner et al., 2006). However, Moeller & Bracko (2004) reported that in female hockey players, carrying a little excess weight for their height may not hamper performance as long as they can effectively skate.

Injury Patterns

Women's collegiate ice hockey has the highest injury rate per athlete exposure of any sport, including men's ice hockey and American football (Pabian, Greeno, Vander Heiden, & Hanney, 2013). Women's ice hockey has a 0.91 injury rate per 1,000 athletic exposures (Pabian et al., 2013). The next highest is American spring football with a rate of 0.54 (Pabian et al., 2013). Despite women's ice hockey being classified as a non-contact sport, approximately 50% of game injuries result from player contact, with another 30% resulting from contact with the boards or the ice surface (Agel, Dick, Nelson, Marshall, & Dompier, 2007). The two most common injuries in women's ice hockey are concussions and groin strains (Moeller & Bracko, 2004; Agel et al., 2007; Agel & Harvey, 2010). Other common injuries include: facial lacerations, fractures of the foot, wrist, and clavicle, and acromioclavicular joint separations (Moeller & Bracko, 2004; Agel & Harvey, 2010; Maffey & Emery, 2007). This paper will not examine these other common injuries because primary treatment is outside of the realm of the strength and conditioning coach. Primary treatment of concussions is also not the job of the strength and conditioning coach; however, it is the most prominent injury in women's ice hockey, and strength coaches are often the first person to interact with an athlete who may have

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suffered a concussion (Pabian et al., 2013).

Concussions are the most prominent injury in women's ice hockey, with concussion rates varying by position: approximately 60% of all concussions occur in forwards, 32-34% in defensive players, and 6-8% in goalies (Agel et al., 2007, Brainard et al., 2012; Moeller & Bracko, 2004). The Concussion in Sport Group (CISG) defines concussion as follows: "Concussion is a brain injury and is defined as a complex physiological process affecting the brain, induced by traumatic biomechanical forces" (McCrory et al., 2012). The CISG released seven common features of concussions, with the most common cause being: "a blow to the head, neck, face, or somewhere else on the body" (McCrory et al., 2012). Interestingly, female ice hockey players have a higher rate of concussions per athlete exposures (AEs) compared to male ice hockey players (0.82/1000 AEs v. 0.72/1000 AEs), despite women's ice hockey being a non-contact sport (Agel & Harvey, 2010). Even more perplexing is that women hockey players experience fewer impacts and impacts resulting in lower head acceleration compared to men's hockey (Brainard et al., 2012). One theory to explain this is that any type of body contact in women's hockey is unexpected; therefore, the athletes are unprepared for the collision, and are at a greater risk for injury (Agel et al., 2007; Agel & Harvey, 2010). Another factor is the differences in neck muscle strength between males and females; average female neck strength is half the neck strength of males (Hildenbrand, K.J., & Vasavada, A.N., 2013). Neck muscle strength is crucial for spine stability and it has recently been suggested that the strength of the cervical neck muscles are a factor in the incident of concussions (Hildenbrand, K.J., & Vasavada, A.N., 2013). However, 80% of the reported concussions in women resulted in less than 10 days off of activity, indicating that the majority of reported concussions are mild (Agel & Harvey, 2010).

The next most common injury in women's ice hockey is groin strains (Agel et al., 2007; Agel & Harvey, 2010; Maffey & Emery, 2007). Groin strains typically occur in sports involving rapid acceleration, sudden changes in direction, and powerful stretching of the leg in abduction and external rotation (Maffey & Emery, 2007). In most hockey players, groin injuries occur primarily from the eccentric force of the adductors required to decelerate the leg during skating stride (Maffey & Emery, 2007). Several factors may be present in diagnosing an injury to the groin or leg adductors: muscle strain, tenderness on palpation of the adductor muscles, hip flexors, and/or lower abdominal muscles, and pain on resisted adduction (Maffey & Emery,

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2007). Risk factors for groin injuries include: decreased hip abduction range of motion, decreased levels of pre-season sport-specific training, and lack of abdominal muscle recruitment (Maffey & Emery, 2007). Furthermore, Maffey & Emery (2007) reported that adductor to abductor strength ratio may also be a risk factor in ice hockey. In fact, players with adductor strength of less than 80% of abductor strength are 17 times more likely to experience an adductor strain (Moeller & Bracko, 2004). Another study found that injured players had 18% less adductor strength than abductor strength compared to non-injured players (Maffey & Emery, 2007). These risk factors suggest that the majority of groin injuries are preventable and can be addressed in off-season conditioning programs. NHL players who had less than 12 sport-specific training sessions in the month prior to training camps were at an increased risk for groin strains (Moeller & Bracko, 2004).

The rate of groin injury in the NHL was 19.87 injuries/100 players/year in the 1996-97 season (Moeller & Bracko, 2004). Groin strains are a non-contact injury, and are even more common in women's hockey (Agel & Harvey, 2010). Therefore, it is important to have good range of motion and an adequate strength ratio between the abductors and adductors prior to the start of the season. Strengthening of the adductors should include both concentric and eccentric strengthening.

Conclusion

Ice hockey requires a precise blend of agility, quickness, speed, power, and strength. The intermittent nature of the sport, combined with the unique nature of on-ice locomotion, makes it one of the most physically demanding sports. It demands superior training and conditioning. Coaches must be aware of the different biomechanics necessary for successful skating, how the stop-start nature of the game affects energy system training, and how to prevent muscular injuries through proper training. Most of the information available on ice-hockey today is from studying men's hockey. Women's hockey is different in that body-contact is not allowed. Coaches must take this into account when designing programs for women's hockey. The purpose of my current study is to use the available research, combined with applicable test data, to design an effective, fully rationalized, year-long training program for a women's hockey team.

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