The Biomechanical Characteristics of Development Age Hockey Players: Determining the Confounding Effects of Body Size on the Assessment of Skating Technique

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A Thesis
Submitted to the School of Graduate Studies & Research
In Partial Fulfilment of the Requirements for the Degree
Master of Science
(Kinesiology)

LAKEHEAD UNIVERSITY
September 24th, 2002

Your file Votre référence
ISBN: 0-612-83430-1
Our file Notre référence
ISBN: 0-612-83430-1

Abstract

Skating ability, and more specifically the ability to accelerate from a stationary position or change direction rapidly, is recognized as one of the most important skills in ice hockey. While coaches may use drills to compare skating performance between individuals, especially during player selection, few studies have identified the essential kinematic variables that contribute to the ability of development age hockey players to accelerate over a specified distance. Previous research reported that the determination of performance and ultimately skating power can be related to specific biomechanical parameters, especially among developing hockey players. Furthermore, there is evidence to suggest considering the potential confounding effects of height and weight in such biomechanical evaluations. Considering the range of variability for the height and weight of ten-year old children, it may be appropriate to include these as predictors of skating performance.

The purpose of this study was to evaluate the biomechanical characteristics of minor hockey players while performing an on-ice acceleration skill test. In addition, the study evaluated the contribution of height and weight on the assessment of skating technique. Participants were 30 male development age hockey players categorized by level of play. The results of the evaluation were consistent with current coaching literature. Correlation analyses identified the kinematic variables related to time to skate six metres. A regression analysis identified the set of variables that best predicted time to skate six metres. The parameters identified in the predictive equation were directly related to the amount of horizontal impulse applied into the ice surface and included the following six parameters: knee angle at push-off 1, 2; knee angle at touch down 1; take-off angle at push-off 1, 2, 3; hip abduction angle at push-off 5; the range of motion of the forward lean angle 2; and player weight.

Overall, the development age hockey players in this study were very similar to their elite adult counterparts in skating patterns with respect to stride characteristics. The differences that were observed were attributed to the differences in size and strength. Comparing structural models across studies further suggests the importance of body size on skating performance.

Acknowledgements

I would like to take this opportunity to thank the many people who have contributed to the completion of this thesis.

To my thesis advisor, Dr. Moira McPherson, for your assistance, guidance, and continued patience throughout this entire research study. Thank-you very much for always encouraging me to continue my education at the Ph.D. level, and helping me find a program that suits my research interests. You have been a role model, and I hope that one day we will be able to work on another research project together.

To the other members of my thesis committee, Dr. William Montelpare and Dr. Jim McAuliffe, for all of your valuable input and advice concerning many different aspects of this project.

To Carlos Zerpa, for your willingness to share your knowledge and expertise on numerous software applications and hardware configurations. The skills you have taught me will always be used in any work I do in the future.

To all of the people who showed up and helped with my data collection. It would have been impossible to complete any of this without the help of Irene, Sarah, Cindy, Dennis, Carlos^2, Joe, Dana, Bill, and Moira.

I would also like to thank my many families for your support and words of encouragement throughout all of my education. Most importantly, I would like to thank my fiancé, Dana, for your continued encouragement, understanding, and patience when listening to me talk endlessly about biomechanical concepts and equipment. Although I know you're not interested, you still politely smile, nod, and say, "Wow! That's really cool!". Without your support, I would have never made it this far.

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Introduction

Currently, young hockey players are selected to the representative teams based primarily on height, weight, and other physical attributes (Montelpare, Scott, & Pelino, 1998). As part of the selection process, coaches also assess specific technical skills. Previous research (Montelpare, Scott, & Pelino, 1996; Barnsley & Thompson, 1988; Shephard, Lavallee, & Lariviere, 1978; Daniel & Janssen, 1987; Barnsley, Thompson, & Barnsley, 1985; Boucher & Mutimer, 1994; Montelpare et al., 1998) has shown that a relative age effect exists within the elite or representative levels of each league, but not within the recreational or house leagues. According to Montelpare et al. (1996), a relative age effect is a difference in chronological age that exists in a defined age category as a result of children having different birth dates throughout the year. For example, in a 12 month age cohort, a child born in January will be almost one full year older than a child born in December. Differences in the rate of change in maturation across an age cohort are expected to accentuate any relative age effects. Considering the range of variability for the height and weight of ten year old children, it may be inappropriate to base player selection solely on these two measures.

It has been stated by many researchers that skating ability is one of the most important skills in hockey, and more specifically, the ability to accelerate from a stationary position or change in direction (Bracko, Fellingham, Hall, Fisher, & Crier, 1988; Kirchner, 1990; Purves, 2000; Marino, 1983). Players are required to perform various skating skills for the purpose of evaluation. Coaches use these drills as a means of comparing skating performance between players. However, there has been very little research that has identified the key kinematic variables that contribute to the ability of development age hockey players to accelerate over a specified distance.

Furthermore, there has been no research which has examined and or compared the technical skills and abilities of house league players versus representative players as determined by the biomechanical characteristics of forward skating. Previous research (Purves, 2000; Marino, 1984) has demonstrated that there is a need to identify kinematic parameters, among developing hockey players, which determine performance and ultimately power. Furthermore, there has been no comparison of these players on specific kinematic parameters with the confounding effect of height and weight eliminated.

Skating Technique

Research (Marino, 1979; Marino, 1984; Marino, 1977; Marino, 1983; Marino & Dillman, 1976; Marino & Weese, 1979; McCaw & Hoshizaki, 1987; Bracko et al., 1988; Purves, 2000) focussed on skating technique has been conducted, however, as Allinger and Van Den Bogert (1997) pointed out, "Although experimental data have been collected to determine the skating technique of the fastest skaters in the world, the 'ideal' skating technique has not been determined." (p. 279). There appears to be little consensus on which specific kinematic variables characterize the ideal skating technique. Research (Marino, 1979; Marino & Weese, 1979; Kirchner, 1990) in this area has often been conducted using small sample sizes and two-dimensional analyses due to the time and technological constraints associated with film and three-dimensional video analysis. Much of the research (Allinger & Van den Bogert, 1997; de Koning, Thomas, Berger, de Groot, & van Ingen Schenau, 1995; de Koning, de Groot, & van Ingen Schenau, 1989) that has been conducted has dealt with the analysis of the speed skating stride, as opposed to the ice-hockey skating stride.

Marino and Weese (1979) selected four participants from the University of Windsor varsity hockey team in order to conduct a film analysis of an ice-hockey stride. The researchers stated that, "Ice skating is bi-phasic with each forward stride consisting of alternate periods of single support [one skate in contact with the ice] and double support [both skates in contact with the ice]." (p. 65). Marino and Weese (1979) measured stride rate, stride length, average horizontal velocity, and single and double support times for each stride. Strides were chosen for analysis based on the criteria that the stride occurred as close to the centre of the filming area as possible. The reported mean average horizontal velocity was 8.78 m/s, with a mean stride rate of 3.54 strides/s, and a mean stride length of 2.48 m. The researchers determined that 18% of the stride was completed during double support, and that a pattern of deceleration started at the end of double support and continued to the midpoint of single support. Participants with greater skill were able to produce propulsive forces during both phases. Acceleration was said to begin with the extension of the hip and knee, and lateral rotation of the hip to create a propulsive angle between the skate blade and the ice. It is interesting to note that the single support phase was not entirely a glide phase, and that forces were summed from the midpoint of single support and released at the end of double support. The results indicate that steady state skating is actually comprised of three distinct phases where propulsion begins at around the midpoint of single support, and continues throughout double support, and then gliding occurs for approximately the first half of single support. Acceleration could not occur until the centre of mass was ahead of the support foot during the double support phase.

Marino (1979) focussed on the kinematic variables associated with acceleration from the filmed performance of a side view. All four of the participants were selected from a physical education class at the University of Illinois. The reported mean time to skate 20 feet was 1.87 s, with a mean instantaneous velocity of 5.08 m/s at the 20 foot mark, and mean average acceleration of 2.72 m/s^2. All of the participants showed a pattern of greater acceleration at the start, which decreased over the distance. Each skater was able to maintain positive acceleration for the first three or four strides, and all the participants required four strides to skate the full 20 feet. Only one of the participants did not undergo deceleration by the end of the distance. The ability to maintain positive acceleration throughout both the single and double support phases was attributed to the recovery foot coming down in a position such that the thigh was already medially rotated creating a propulsive angle between the skate blade and ice. When compared to Marino and Weese's previous study, these results highlighted the differences in the biomechanical characteristics of an ice-skating start versus a steady state stride. However, the researcher did point out that future analyses were needed to further explore the relationship between specific kinematic variables and acceleration.

Marino (1983) further studied on-ice acceleration from a forward standing start with the use of two cameras. One of the cameras was set-up to film a side view of the six metres testing area, and the second camera was placed above the field width in order to assess the impact of lateral movements on the performance. The participants varied greatly in skill, with 14 participants coming from the University of Illinois's club hockey team, and 55 volunteers from hockey classes and intramural teams. All participants completed three trials, the fastest of which was utilized for the analysis. As a pattern of glide and deceleration was apparent after the first three or four strides, Marino selected only the first three strides for the analysis to best represented rapid acceleration. For the purpose of the analysis, push-off was defined as the point at which the skate blade left the ice following double support, and touch-down was defined as the point at which the skate blade contacted the ice after recovery. Marino measured the participant's weight, height, standing leg length, as well as stride length, single support time, double support time, stride rate, vertical displacement of the recovery foot, toe-to-hip distance at touchdown, hip angle at push-off, knee angle at push-off, angle of push-off, lean angle of push-off, lean angle at touchdown, and the propulsive angle of the skate blade. The reported mean time to skate six metres was 1.95 s, with a velocity of 5.75 m/s at the six metre mark, and a mean average acceleration of 2.96 m/s^2. From the Pearson product moment correlations, Marino was able to determine that shorter single support time, toe placement directly under the hip after recovery, and full extension of the knee prior to push-off all resulted in greater velocities. A forward selection, stepwise regression indicated that increased forward lean, a lower angle of push-off, increased stride rate, and height best predicted time to skate 6 metres. Marino's results support previous analysis by Marino and Dillman (1976). The relationship between stride length and acceleration was found to not be significant. Overall, the best skating technique for the achievement of high rates of acceleration should consist of a high stride rate, increased forward lean at touch-down, short single support phases, and the placement of the recovery foot below the hip (Marino, 1983).

Marino (1983) identified stride rate as one of the best predictors of time to skate six metres, and a large propulsive angle was positively correlated to this. Kirchner (1990) sought to study the relationship of the ankle with forward acceleration in ice hockey. Two elite level athletes were selected from a sample of 25 to complete the protocol. Participants completed 10 trials of maximal acceleration, where the skate was filmed by two cameras during the fourth stride. In order for propulsion to occur, the skate blade must be positioned such that it is angled away from the desired line of motion. A relative velocity was created between the skate and the centre of mass, as they both travel in opposite directions. As relative velocity increases, leg extension occurs more rapidly, resulting in the reduction of force production. The opposite is true as well. Forward lean was identified to be important in the production of force, as this creates a greater horizontal component to the force that is directed to the ice surface. Kirchner's results are important as they support and help to explain the results that Marino (1983) reported. If the ideal method of skating to increase acceleration involves a rapid stride rate, then forward lean has to increase in order to produce greater forces into the ice, which will offset the force production deficit created by a fast stride.

Although the literature suggests a consensus on the specific kinematic variables that best characterize skating technique, all of the studies have been conducted using film analysis in two-dimensional space. According to de Koning et al. (1989), movements during the skating start occur in three-dimensions and a special analysis is required. Purves (2000) conducted a three-dimensional analysis utilizing 37 professional hockey prospects from the Florida Panthers and Los Angeles Kings of the NHL. Two Panasonic CL-350 digital cameras were mounted on Peak Performance Pan and Tilt Heads, and positioned to videotape a maximal acceleration test. Each participant was taped completing two trials, and the faster of the two was utilized for analysis. Both tapes were then digitized using the Peak5 Video Analysis software housed at Lakehead University, and the resultant data files were smoothed utilizing a 4^{th} order Butterworth optimal frequency filter. The smoothed data was then combined through a Direct Linear Transform to form a three-dimensional image.

Purves (2000) measured the participants' age, height, weight, as well as peak anaerobic power, anaerobic capacity, instantaneous velocity, average acceleration, time, and specific kinematic variables at push-off and touch-down for each of the first five strides. The reported mean time to skate 6.06 m was 1.22 s, with an average instantaneous velocity of 6.44 m/s at the 6.06 m mark, and a mean average acceleration of 2.09 m/s^2 over the distance. Through exploratory principle factor analysis (PCA), nine of the original seventeen kinematic variables were eliminated from further analyses. Another PCA was then performed which identified three distinct latent variables that had a factor loading greater than 0.06. From the three latent variables, Purves identified six "variable sets" that corresponded to groups of kinematic characteristics and eight "isolated variables" that corresponded to individual kinematic characteristics. All of the variables identified through this procedure, along with height, weight, and peak anaerobic power, where then utilized using a backward stepwise multiple regression analysis. The following regression equation was calculated:

Equation 1. Purves' regression equation for time to skate six metres (Purves, 2000; p. 40)

$$y_i = 0.291 + 0.845x_1 - 0.016\,x_2 + 0.007\,x_3 + 0.007\,x_4 + 0.453\,x_5 - 1.500\,x_6 - 1.688\,x_7 - 0.006\,x_8 - 0.004\,x_9$$

where: x_1 = player height
x_2 = peak anaerobic power (normalized)
x_3 = knee angle (1st push-off)
x_4 = hip abduction at push-off (strides 4,5)
x_5 = propulsive time (strides 2,3,4)
x_6 = stride length (strides 1,2,3)
x_7 = toe-to-centre of mass distance (3rd touchdown)
x_8 = hip angle (1st push-off)
x_9 = hip abduction (2nd push-off)

The regression equation that Purves (2000) developed was much different than the equation that was developed by Marino (1983). The difference in results can be attributed to the difference in data processing techniques, the sample of participants analysed, and the technique of motion capture used. One of the most obvious differences was the exclusion of stride rate in the Purves equation, and the exclusion of stride length in the Marino equation. Although the results from Purves (2000) suggest that players tended to use short, rapid strides at the start of acceleration, much like reported in Marino (1983), the two researchers came to different conclusions as to the importance of stride length versus stride rate. Upon examination of the related literature, including the work of McCaw and Hoshizaki (1987) and Marino (1977), the consensus is that stride rate is positively correlated to skating velocity, and not stride length.

The Skating Characteristics of Development Age Hockey Players

There has been little research conducted in the area of defining the biomechanical characteristics of children performing ice-skating techniques. In the only located published study Marino (1984) selected a sample of 174 youth skaters, ranging in age from 8-15 years old. The participants were grouped into age categories, and filmed over a four metre distance. Trials were selected for analysis based on completing the task with a uniform skating pattern, without deviation from a straight line. Since the younger players were generally unable to complete the protocol as desired, the selection criteria yielded 104 trials suitable for analysis. Horizontal skating velocity, stride rate, stride length, support times, angle of take-off, and the angle of trunk lean at take-off were all measured. The reported mean maximum velocities ranged from 4.7 m/s to 7.13 m/s, with stride rates between 2.99 strides/s and 3.10 strides/s, along with a stride length of 1.54 m to 2.37 m. There was a significant increase with maximal velocity as age increased, as well as for stride length. The eight year old group showed significant differences with respect to mean skating velocity and mean stride length to all other groups. As well, the nine year old group showed the same significant relationships to the groups of 13, 14, and 15. Marino attributed the increase in skating velocity to stride length, as there was no significant relationship between stride rate and velocity. As the researcher pointed out, stride length is representative of the power of the thrust during propulsion, therefore players that were able to generate more power were able to achieve greater velocities. There was a reported range of 42.1° to 60.3° of forward lean angle, with a significant difference between the eight year old group and the 11, 12, 13, 14, and 15 year old groups. Players that were able to achieve a lower forward lean angle at push-off, were able to travel at greater horizontal velocities.

From all of the results, Marino determined that, "By the age of eight, the forward ice skating pattern has been developed to the point beyond which changes in skating velocity are associated mainly with increases in stride length rather than stride rate" (1984, p. 7). As well, "...the basic skating pattern has developed by age ten and that subsequent changes in basic mechanics reflect changes in strength and power associated with growth and development patterns." (Marino, 1984, p. 8). The results reflected a need to further examine the specific biomechanical factors associated with ice-skating for developing hockey players.

While there was no other research found which focussed on the biomechanical characteristics of development age hockey players, it is possible to examine literature focussed on the coaching of youth hockey players in order to gain information on characteristics of the skating stride. From Chambers' book *Complete Hockey Instruction: Skills and Strategies for Coaches and Players* (1989), the ideal skating technique is described as being well balanced, with feet shoulder width apart, and having the thrusting leg laterally rotated. At the end of propulsion, the driving leg should be fully extended, right down to the ankle, and the upper body and gliding leg should form a 90° angle at the hip. The recovery foot should be kept close to the ice, all while maintaining a smooth swing of the arms. Chambers also provides the following description of a front-style start. The driving leg is positioned so that the skate blade is perpendicular to the direction of travel, and the body leans forward, over top of the front foot. Strides must be kept short and quick in order to achieve a maximal stride length as soon as possible. Although the previous description does not take into account body size, Chambers does stress at the start of the book that physical size is an important attribute, and must be considered with skating speed and agility. Furthermore, Vaz (1982) reported that when hockey players ranging in age from 7-16 years of age were asked what the coaches of an All Star Team look for in players, the top three responses were:

1) Ability to Skate and Shoot

2) Being Aggressive

3) Physical Strength and Size (p. 177)

Vaz's results illustrate the importance size is given during the technique assessment of development age hockey players. One of the many variables that has been consistently defined as a major contributing factor to a players ability to accelerate has been player height (Purves, 2000; Marino, 1983, Marino, 1984). The importance placed on player height has led to the exclusion of players from the elite level at a young age due to a lack in physical development, which has been identified to be related to birth month (Baxter-Jones et al., 1994)

The Relative Age Effect related to Growth and Development

Although the relative age effect has been researched extensively in minor hockey over the past 15 years, it was first identified by Shephard et al. (1978). They found that the Trois Rivieres hockey league grouped players into two year age categories, and that the older age categories contained boys with greater stature, a larger relative weight, a higher physical work capacity, and above average physical strength. Shephard et al.'s study did not take into account birth dates, but they found that as players progressed through the league, the variance in stature decreased. According to Barnsley et al. (1985), age groups are designed to equalize competition and facilitate instruction. However, grouping children based solely on age tends to create age and maturational discrepancies within an age cohort. If a relative age effect occurred in minor hockey (Shephard et al., 1978), then one might expect evidence of such a phenomenon at the higher levels. A relative age effect is indicated by a decrease in the number of players with birth dates in the later half of the year. The remaining players would therefore be relatively close in stature and weight. The relative age effect is caused by the selection of more maturationally advanced players prior to puberty, which has been shown by Lariviere, Nicoletti, Bossi, and Milani (1993) to favour players born in the first half of the year.

Barnsley and colleagues (1985) examined the birth records of players from three major hockey leagues, the National Hockey League (NHL), Ontario Hockey League (OHL), and the Western Hockey League (WHL). The researchers tabulated birth dates by birth month, which yielded a frequency distribution. Barnsley et al. found that for the NHL, the frequency of birth dates was highest in January, and declined throughout the year. A similar pattern was evident in the OHL, and WHL as well. Results from analysis showed that in the NHL, players were twice as likely to be born in the first half of the year compared to the last, for the WHL, players were four times as likely to be born in the first quarter than the last quarter, and 3.5 times for the OHL. Rank order correlations were calculated for all three leagues in order to determine if a greater number of birth dates occurred in January, and progressively decreased to December. The results for the NHL were 0.89, 0.99 for the WHL, and 0.98 for the OHL, indicating that there was a strong correlation between the frequency of birth dates being greatest at the start of a calendar year, and progressively declining until the end of the same year. The researchers proposed that this was the result of a developmental advantage held by those players born in the earlier months of the year when they were in minor hockey.

Barnsley et al.'s (1985) conclusion as to the cause of declining frequencies of birth dates throughout a calendar year was supported by the work of Rahkila et al. in 1988. Rahkila and associates (1988) studied nine year old hockey players that competed in a junior league in the city of Jynaskyla, Finland. The sample consisted of 37 males and 1 female. The researchers measured height, weight, sum of skinfolds, grip strength, leg power, maximum oxygen uptake, lactate levels, and x-rays. Rahkila et al. determined that the mean skeletal and mean chronological ages were almost identical for the group. However, mean chronological age had a range of 1.1 years, whereas mean skeletal age had a range of 4.6 years. From this data, the researchers classified players with a skeletal age of ±1 year from their chronological age as average, with the rest of the players falling into delayed or advanced groups accordingly. Proportions were then determined, where 31% of the players were delayed, 49% where average, and 20% were advanced. Correlations were calculated between skeletal age and height, weight, BMI, and grip strength. The results were 0.79, 0.75, 0.61, and 0.52 respectively illustrating how players with delayed maturation as compared to chronological age will be shorter in stature, with a lower relative weight, and lower grip strength. Conversely, players with advanced maturation as compared to chronological age will be of greater stature, with a larger relative weight, and greater grip strength. Therefore, at the age of nine, players that have birth dates at the beginning of the year will be more maturationally advanced, and will have a greater chance of being selected to the elite level. Selection based on anthropometric measures will result in a greater number of players at the elite level in older age groups with birth dates from the start of the year, as was found by Barnsley and co-workers in 1985.

Barnsley and Thompson (1988) studied the affect that a relative age effect has on players competing in minor hockey. They explored this problem with a two part study. The first part examined how birth date affected participation in minor hockey. The researchers contended that having a relative age advantage leads to greater success at a young age, which then leads to a better perceived experience in the sport, greater rewards, and opportunities for better coaching and competition. When the birth dates for players competing in the Edmonton Minor Hockey Association (EMHA) were examined for the 1983-1984 season, Barnsley and Thompson found that for the early levels of MiteF, Mite, and Junior, there was no significant relationship between month of birth and participation. However, a relative age effect did exist for the older levels of Pee Wee, Bantam, Midget, and Juvenile. The impact of these findings was illustrated by Cunningham in 1979. Selection to the elite levels, resulted in better coaching and more time on ice for practice and competition, just as Barnsley and Thompson (1988) suggested. Cunningham (1979) sought to determine the cardiorespiratory responses of elite level minor hockey players compared to non-elite level minor hockey players. Such a comparison would further explore the physiological effects of the improved training opportunities associated with the elite level. The researcher selected two groups of nine year old boys, divided by level of play in hockey. Although there was a great amount of difficulty reported with respect to the participants being able to complete the testing protocol, Cunningham was able to draw conclusions based on previous research and some of the data collected. It was found that the elite player exhibited a greater maximal oxygen uptake, as well as greater levels of post exercise blood lactate. The results suggested that even at a young age, hockey players that are selected to the elite levels benefit physically from the advantages afforded to them.

The second part of the Barnsley and Thompson study (1988) was an analysis of success using the same sample. When the players were analysed for birth date versus level of play, an interesting trend was found. The bottom tier of players consisted of a higher proportion of birth dates from the second half of the year, representing players with a relative age disadvantage (Barnsley & Thompson, 1988). The middle tier of players consisted of an even distribution of birth dates, and the top tier consisted of a higher proportion of birth dates from the first half of the year (Barnsley & Thompson, 1988). These results were further supported by Boucher and Mutimer (1994), who examined the birth records of all the members of elite A and AAA hockey teams in the province of Nova Scotia during the 1988-89 regular season. The sample consisted of 951 players, ranging in age from 8-17 years old. A significant relationship between relative age and participation on the elite teams was found for all of the age levels. Furthermore, the distribution of the birth dates across a birth year were not evenly distributed as expected, but rather favoured the early months (Boucher & Mutimer, 1994). Both studies illustrate how children born earlier in the year achieved greater success in hockey at the minor level. Success at the minor level provides those players with the opportunity to achieve success when progressing to the older age divisions.

According to Montelpare, Scott, and Pelino (1998), age determination dates create a relative age effect, and this in turn favours children that are more maturationally developed. If the selection of developmentally advanced players to the elite level is the result of a relative age effect, then it would be expected that house leagues would not present such a phenomenon, due to the absence of player selection. All players that register for hockey are guaranteed to play, and those players not selected for the representative teams are placed in the house level. Montelpare, Scott, and Pelino (1996) reported similar findings to Barnsley et al. (1985), Barnsley and Thompson (1988), and Boucher and Mutimer (1994) for players participating at the elite level of hockey, across a wide age range. For the 1995-1996 season, more than 62% of the players competing in the CIAU, 66% of the players competing in the OHL, 62% of the players competing in rep. leagues in the Minor Hockey Association of Calgary (MHAC), and 64% of the players competing in the NHL had birth days in the first half of the year. By contrast, players from the house league competing in the MHAC only had 53% of their birth dates in the first half of the year over the same season (Montelpare et al., 1996). The reported results indicate that a relative age effect does exist in the elite levels of hockey, and not in the house leagues.

Furthermore, Montelpare, Scott, & Pelino (1998) reported similar findings over a broader spectrum of leagues and levels. The research completed by Montelpare and co-workers found supporting evidence for a relative age effect across five different levels of elite hockey, including the OHL, CIAU, NHL, Canadian Minor Hockey Association (CMHA), and the IIHF's World Junior Ice Hockey Championships. The researchers also found no indication of a relative age effect occurring in the house level of the CMHA.

Daniel and Janssen (1987) further explored the relative age effect in hockey by trying to trace when it began to occur. They studied the birth dates for NHL players over four seasons during the 1960's and 1970's. According to Daniel and Janssen (1987), prior to the 1974-75 season, a relative age effect did not occur in elite levels of junior hockey, or in the NHL. However, by the 1982-83 season, a relative age effect appeared at the junior level, and by the 1985-86 season, it was also evident in the NHL. The researchers proposed that the 1972 Soviet Union series led to more structure in the development level of minor hockey in Canada. The emphasis was placed on streaming children into elite levels in order to identify and improve on talent. Players entering into this system had not reached puberty yet, and researchers have been able to identify that up until the age of 14, skeletal age, psychological age, emotional maturity, and physical work capacity are all extremely variable, and are significantly correlated with biological age and not chronological age (Baxter-Jones, Helms, Baines-Preece & Preece, 1994; Baxter-Jones, 1995; Lintunen, Rahkila, Silvennoinen & Osterback, 1988; Rahkila, Lintunen, Silvennoinen & Osterback, 1988; Cunningham, 1979; Meleski, Malina & Bouchard, 1981). As Malina (1988) suggests, the concept of maturity differs slightly from growth because, in order to obtain a true sense of someone's maturational level, a researcher must consider sexual, skeletal, and somatic maturity together. However, it is time consuming and impractical to complete all of these tests for each participant, so quite often just one factor is used in order to describe a child's maturational level. Players that have a relative age advantage would be more maturationally developed, leading to a physical, psychological, and emotional advantage.

Evidence of player selection based on maturational development was presented by Lariviere and colleagues (1993), who assessed the chronological and skeletal ages of 108 elite male Bantam hockey players. They found that although chronological age decreased progressively from the start of the year to the end, there were no significant differences for height, weight, or sum of skinfolds. Furthermore, there were no significant differences for fitness measures, or technique skills. However, there was a significant difference for skeletal age between the first 3 quartiles of the year compared to the last quartile. Skeletal age varied from 1.13 to 2.05 years away from chronological age. All participants obtained above average scores for Canadian ice hockey players of a similar age on all measures, and ranked in the 80th percentile for weight and height. If the same scale was used as in Rahkila et al. (1988), then there would be a larger proportion of advanced and average athletes, as compared to a larger proportion of delayed and average athletes. The researchers stated that their results reflect the importance that body size has for coaches as an indicator for performance (Lariviere et al., 1993).

There has also been evidence presented by DiPasquale, Moule, and Flewelling (1980) that shows how early maturing children also gain a readiness to learn advantage. When the researchers assessed the records of students referred for psychological assessment due to problems in the classroom and delayed learning, they found an association between birth month, and referrals, largely due to the kindergarten level. The later the birth month, the more referrals. Furthermore, Lintunen and associates (1988) found that early maturing boys had a significantly higher physical self-concept, higher self-esteem, and were less anxious.

A development age minor hockey league that promotes the selection of players for elite calibre competition before puberty, favours those children born earlier in a calendar year. Daniel and Janssen (1987) further reported that by 1980, the products of this new system had progressed to the NHL, thus creating a relative age effect at that level as well. According to Daniel and Janssen (1987), the classification of young children into age groups, along with the streaming of prepubescent children into elite levels of competition, has caused a relative age effect. If other sports are examined that have selection to elite levels after puberty, or else do not even start until after puberty, than a relative age effect should not occur. When birth dates were examined from the Canadian Football League (CFL) and the National Football League (NFL) for the 1984-85 season, no relative age effect was found (Daniel & Janssen, 1987). Although the physical demands of football are very similar to those of hockey, organized play does not begin until the age of 12, and streaming does not occur until the collegiate level. As well, the categorization of players is based not only on age, but on height and weight also. The same held true for the National Basketball Association (NBA) and for Major League Baseball (MLB) over the same period of time.

As Marino and Weese (1979) stated, "The refinement and improvement of ice skating technique...demands detailed knowledge of the mechanical characteristics of the ice skating movement patterns." (p. 65). Previous research (Marino & Weese, 1979; Marino, 1979; Marino, 1983; Purves, 2000) reported that the determination of performance and ultimately skating power could be related to specific biomechanical parameters. Purves (2000) and Marino (1984) have further reported a need to identify the specific kinematic parameters of the ice-skating stride for the development age. While coaches may use drills to compare skating performance between individuals, especially during player selection, few studies have identified the essential variables that contribute to the ability of development age hockey players to accelerate over a specified distance. There has also been evidence presented to consider the potential confounding effects of height and weight in such biomechanical evaluations. Rahkila et al. (1988) reported on the range of maturation in a single age cohort of youth ice-hockey players in Finland. Considering the range of variability for the height and weight of ten-year old children, it may be inappropriate to include these as predictors of skating performance. Furthermore, a relative age effect has been identified in elite levels of hockey across all age cohorts (Boucher and Mutimer, 1994). As a result of the growth and maturation rate at the development age, players with a relative age advantage could be more maturationally developed, leading to a physical, psychological, and emotional advantage. Therefore, it is necessary to determine the confounding effects body size has on the assessment of skill.

Statement of Purpose

The purpose of this study was to systematically evaluate and describe the biomechanical characteristics of 10 year old minor hockey players while performing an on-ice acceleration skill test. A secondary purpose of this research was to evaluate any possible confounding effects of height and weight on skating technique.

Participants

The participants for this study consisted of 30 male 10 year old hockey players, categorized by level of play, currently registered in the Port Arthur Minor Hockey Association (PAMHA). Seventeen of the players were currently playing for teams selected into representative hockey, and 13 of the players were currently playing for teams selected out of representative hockey. The current president of the PAMHA, Mr. Frank Zanatta, was contacted in order to assist with the identification of potential participants. Based on his support, the parents of potential participants were contacted, and asked to speak with their children about attending the testing. At the time of testing, a cover letter (presented in Appendix A) and letter of informed consent (presented in Appendix B) outlining the purpose, risks, and potential benefits associated with this study was distributed and collected.

Methodology

On-Ice Acceleration Test

In order to assess the player's skating technique, the participants were required to complete an on-ice acceleration skill test. The testing sequence outlined by Purves (2000) was modified to better suit the requirements of this study. The protocol used was as follows:

Table 1
On-ice acceleration test protocol

Period	Time/Length	Activity
Warm-Up I	5 minutes	Skating at low-medium intensity
	5 minutes	Gentle stretching of major muscles; focussing on quadriceps, hamstrings, groin, calves
Warm-Up II	3-5 minutes	Skating at low intensity, with 4-5 sprints of 4-5 seconds
Video-Taped Trial I	18 metres	Maximal acceleration from stationary position, throughout full distance upon signal
Rest	3-5 minutes	Skating at low intensity; light stretching
Video-Taped Trail II	18 metres	Maximal acceleration from stationary position, throughout full distance upon signal
Rest	3-5 minutes	Skating at low intensity; light stretching
Video-Taped Trial III	18 metres	Maximal acceleration from stationary position, throughout full distance upon signal
Cool Down	3-5 minutes	Skating at low intensity

Two different lanes were set-up on the ice in order to minimize the effects of ice condition deterioration on performance.

Videography

The on-ice acceleration test was taped for each participant using two, Panasonic CL-350 digital cameras mounted on Peak Performance Pan/Tilt heads that were fixed to surveying tripods and gen-locked using a Peak Performance Event Synchronization Unit (ESU) according to the guidelines set forth in the Peak Motus® Version 7.0 User Manual. A Society of Motion Picture and Television Engineers (SMPTE) time code was imprinted during recording in order to enable the matching of camera views during digitizing. In order to ensure the players did not "let-up" before the finish line, the participants were instructed to skate a distance of 12 metres greater than necessary, as fast as possible. The fastest of the completed trials in both camera views was used for the subsequent analysis. The set-up of the cameras was as follows:

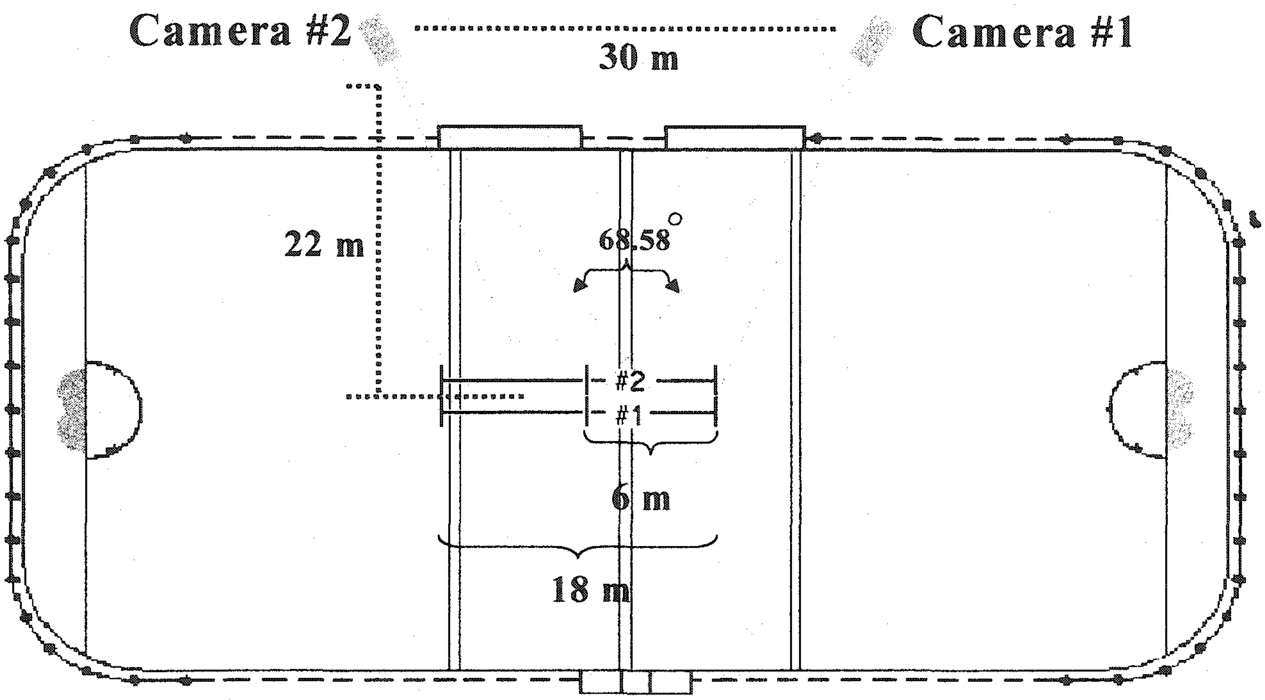

Figure 1. Camera set-up

Along with the on-ice acceleration test, participants' parents were required to complete a Player Profile form. This form supplied all of the necessary supplemental information required for the analysis. An example of the Player Profile form is presented in Appendix C.

Video Analysis

The recorded videotapes were manually digitized using the Peak Motus® Pan and Tilt Module software located in the Lakehead University Research Centre, according to the 23-point spatial model in Appendix D.

Identification of Event Frames

For the purposes of this study, 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. In order to reduce the amount of time required to digitize the trials, the following 15 critical event frames were identified and digitized for each participant for each camera view:

1) Push-off for strides 1 through 5

2) Touch-down for strides 1 through 5

3) The maximum height attained by the recovery foot for strides 1 through 5

The frame counter, found on the Peak Motus® information bar was used to identify and match the critical events between camera views. The three-dimensional space was calibrated according to the guidelines set forth in the Peak Motus® Version 7.0 User Manual, using four eight foot calibration poles. The poles were spaced two metres apart, across a distance of eight metres between the skating lanes. Once all of the events had been digitized, data was combined using a Direct Linear Transform (DLT) in order to render a computer generated three-dimensional image. This process supplied all of the information used to determine the specific joint angles, segmental displacements, the displacement, velocity, and acceleration of the centre of mass, and stride characteristics. Table 2 lists the kinematic variables of interest, and Appendix E: Figures E1, E2, E3, and E4 illustrate the same.

Table 2
Kinematic variables of interest

Variable Name	Description	Label*†
Hip Angle	Angle between the trunk and thigh of push-off side	HA-p#
Hip Angle	Angle between the trunk and thigh of touchdown side	HA-t#
Forward Lean Angle	Angle between the trunk and horizontal of push-off side	FLA-p#
Forward Lean Angle	Angle between the trunk and horizontal of touchdown side	FLA-t#
Knee Angle	Angle between the thigh and shank at push-off	KA-p#
Knee Angle	Angle between the thigh and shank at touchdown	KA-t#
Ankle Angle	Angle between the foot and shank at push-off	AA-p#
Skate-V Angle	Angle between the skate blades at touchdown	SV-t#
Propulsive Angle	Angle between the skate blade and the direction of travel at push-off	PA-p#
Take-Off Angle	Angle above the horizontal of a line from the toe of the boot to the hip at push-off	TOA-p#
Hip Abduction Angle	Angle between the thigh and the vertical plane at push-off	HAB-p#
Shoulder Flexion/Extension	Angle between the humerus and the YZ plane	SF/E-p#
Shoulder Abduction/Adduction	Angle between the humerus and the XY plane	SA/A-p#
Stride Rate	The number of strides per second	SR#
Stride Length	The horizontal distance from push-off of one leg to push-off of the other	SL#
Propulsive Time	The time taken from touchdown of skate to push-off of same skate	PT#
Double Support Time	The time during which both skates are in contact with the ice during a stride	DST#
Height of Centre of Mass	The height above the right skate tip at touchdown	HCM-t#
Maximum Height of Recovery Foot	The maximum vertical displacement of the foot during recovery	MHRF#
Hip Angle Range	The range in motion of the hip from touchdown to push-off	HA.t-p#
Knee Angle Range	The range in motion of the knee from touchdown to push-off	KA.t-p#
Forward Lean Angle Range	The range in motion of the trunk with respect to the horizontal from touchdown to push-off	LA.t-p#

* - measures taken at the event of push-off are denoted with –p#
† - measures taken at the event of touchdown are denoted with –t#

Statistical Analyses

Intraclass coefficients for reliability. The consistency of the digitising over the course of a day was measured using intraclass coefficients for reliability.

Descriptive statistics. Descriptive statistics were computed for the kinematic parameters in order to summarize and describe the sample used in this study. The minimum and maximum values, along with the mean, standard deviation, skewness, and kurtosis for all variable sets were included. The set of mean values that corresponded to mean values derived from the kinematic parameters as defined by Purves (2000) were compared graphically in order to gain insight into the differences between development age hockey players and elite professional athletes.

Independent samples t-tests. Nine independent samples t-tests were used to determine the differences in means between the two skill levels with respect to time to skate six metres, delay time, height, weight, average horizontal velocity over five strides, and between position played with respect to time to skate six metres, height, weight, and average horizontal velocity over five strides.

Bivariate correlations and regression. Bivariate correlations were used to identify which kinematic variables were significantly correlated with time to skate six metres and average horizontal velocity over five strides. All of the kinematic variables identified in the previous step were entered into a multiple regression backward stepwise analysis with player height and weight in order to determine the set of variables that best predict time to skate six metres. Once the set of best predictors had been identified, variables that occurred as either a pair, or as a set of three or more, were transformed in order to preserve the uniqueness of each variable in the set. Variables that occurred in pairs (i.e. hip angle at touchdown for stride one and two) were transformed by calculating the slope of the line between the values, and any variables that occurred in multiples (i.e. take-off angle at push-off for strides one, two, and three) were transformed by calculating the slope of the log-log transformation of the power function (see Equation 2 and Equation 3) through the origin (Stevens, 1957).

Equation 2. Power function

$\psi_i = k\ \phi_i^{\beta}$

Equation 3. Log-log transformation of the power function

$\log \psi_i = \log k + \beta_i \log \phi_i$

where: ψ_i = the dependent measure
ϕ_i = the measurement interval
k = a constant set to 1
β_i = the exponent of the power function

The effect of body size on skating technique assessment. In order to assess whether or not a relative age effect existed in the present study, the calendar year was divided into quartiles of three-month groupings beginning with January. Frequency tables of birth dates across quartiles for both levels of play were then created. In order to gain insight into the confounding effect of body size on the assessment of skating technique as it relates to the relative age effect and growth and development, structural models which were developed for male university aged hockey players, and male elite NHL rookie prospects, were compared to the model generated in the present study.

Results and Discussion

Intraclass Coefficients for Reliability

The consistency of the digitising over the course of each day was established using an estimation of the intraclass coefficients for reliability. No significant differences were observed for any F-test comparisons (p>0.05).

Descriptive Statistics on the Sample

Table 3 displays the descriptive statistics for the anthropometric measures of the players in this study compared to those reported by Rahkila et al. (1988).

Table 3
Anthropometric measures

Variable	Present Study	Rahkila et al. (1988)
	$\bar{x} \pm s$	$\bar{x} \pm s$
Age (years)	10.00 ± 0.00	9.30 ± 1.30
Height (cm)	145.12 ± 6.39	136.00 ± 6.00
Weight (kg)	36.09 ± 6.49	31.50 ± 6.20

The complete set of results, including values for skewnes and kurtosis, were computed using SPSS 10.0 for Windows and are presented in Appendix F. The mean weight of forwards was 35.3 ± 6.22 kg with a mean height of 144.53 ± 6.8 cm. Defensemen had slightly higher reported values for mean weight 38.92 ± 7.3 kg with a mean height of 146.69 ± 6.18 cm. The results for the pooled sample are similar to those reported in Rahkila et al. (1988). The slight differences in results can be attributed to the older participants tested in the present study. Although there was no literature found reporting the difference in body size between development age hockey players with respect to position played, Meleski and Malina (1981), who measured cortical bone size, did report that defencemen ranging in age from 10 to 12 years of age had a larger body size than forwards from the same age group. Therefore, the physical characteristics of the sample in the present study were expected.

Description of the Development Age Skating Technique

Through the review of literature, there were no studies found that reported any kinematic data for the ice skating stride of development age hockey players during forward acceleration. The results were, therefore, compared to results reported for older age groups. Marino (1983) suggested that both time to completion and horizontal velocity should be considered when analysing a skill for optimal performance. It was found that in the present study, the time to skate six metres was actually comprised of three distinct phases. The first phase was a delay time during which the participants performed some form of movement after commencing forward motion, but before pushing-off for the first time. A number of actions occurred during the delay phase such as a shifting of the feet while in contact with the ice, lifting and the subsequent replacement of the feet prior to push-off, the placement and sometimes removal of the hands from the stick, and rotation of the trunk for the purpose of looking into the spectator area. The movements that occurred were inconsistent across trials for each subject, as well as between subjects. The second phase was the actual time required by the participant to perform five strides. The third phase was the time required from the completion of five strides to the six-metre mark. It was determined that a standardized value for horizontal velocity could be calculated by taking the change in horizontal displacement of the centre of mass from the first push-off to the last touchdown and dividing it by the time to perform five strides.

Table 4 displays the descriptive statistics for the time to skate six metres and average horizontal velocity over five strides for the players in the present study as compared to those reported in Purves (2000) and Marino (1983).

Table 4
Time to skate six metres and average horizontal velocity over five strides

Variable	Present Study $\bar{x} \pm s$	Purves (2000) $\bar{x} \pm s$	Marino (1983) $\bar{x} \pm s$
Time to Skate Six Metres (s)	2.05 ± 0.14	1.22 ± 0.11	1.95 ± 0.13
Average Horizontal Velocity Over Five Strides (m/s)	3.52 ± 0.27	----- ± -----	----- ± -----

Neither Purves nor Marino reported mean average velocities over the defined distance, but rather reported mean instantaneous velocities at the six-metre mark of 6.44 m/sec (Purves, 2000), and 5.33 m/sec (Marino, 1983). The difference observed in performance time from the three studies can be attributed to the differences in skating ability of the participants tested. Purves (2000) tested NHL rookie prospects at a summer camp, while Marino tested varsity and intramural university hockey players. Marino (1983) also reported that the starting position on the ice was the same for each participant, whereas in the present study, there was some minor inter-subject variability on the starting point and position.

Marino and Dillman (1976), Marino (1983), and Purves (2000) reported that higher rates of skating velocity achieved through greater changes in acceleration are a result of a number of factors, including the stride characteristics. In order for acceleration to occur, the strides must be quick and short. The amount of time that the athletes are in double support, the length of the strides, and the propulsive time are indications of stride characteristics. Table 5 displays the descriptive statistics for the mean double support time, mean stride length, and mean propulsive time for the players in the present study as compared to those reported in Purves (2000) and Marino (1983).

Table 5
Double support time, stride length, and propulsive time

	Present Study		Purves (2000)		Marino (1983)
Variable	St.1 ⇒ St.5*	△†	St.1 ⇒ St.5*	△†	$\bar{x} \pm s$
Double Support Time (s)	0.02 ⇒ 0.04	0.02	-0.02 ⇒ 0.00	0.02	0.04 ± 0.02
Stride Length (m)	1.24 ⇒ 1.91	0.67	1.02 ⇒ 1.85	0.83	1.11 ± 0.21
Propulsive Time (s)	0.30 ⇒ 0.34	0.04	0.25 ⇒ 0.30	0.05	----- ± -----

* - represents the progression from the first stride to the fifth stride
† - △ represents the change in the parameter from the first to fifth stride

A higher stride rate requires the athlete to push-off quickly and subsequently place the recovery foot down quickly in order to prevent falling forward. These movements, much like running, result in the generation of a flight phase. Considering the calibre of athletes tested in Purves' study, it is not surprising to note that on average no double support phase existed during the first five strides. However, the length of flight time decreased over time. The development age hockey players in the present study had a double support phase that consistently increased in time. Marino and Dillman (1976) stated that at higher rates of acceleration, no double support phase existed. Stride length and propulsive time are both indicators of the amount of impulse being applied to the ice surface. Impulse is a function of the force application over a period of time. The larger and more technically advanced participants in the Purves study were able to apply a greater force in a shorter period of time than the participants in the present study due to differences in limb length, body mass, and peak anaerobic power. The mean stride rate in the present study was 2.9 ± 0.29 strides/s as compared to the mean stride rate of 3.31 ± 0.39 strides/s as reported by Marino (1983). As suggested by Purves (2000), stride rate is directly related to skill level, and the amount of power generated with each stride. The results of the comparison of kinematic data between studies indicate a difference between the three groups with respect to the magnitude of selected kinematic parameters that are most likely a function of size and strength.

In order to achieve high rates of acceleration, it is imperative that the horizontal component of the force vector being directed into the ice be maximized (Kirchner, 1990). Although no proven technique for accurately measuring ground reaction forces applied to a skating surface has been developed yet, it is possible to assess the proficiency of a skater in creating horizontal force by examining their stride characteristics at push-off. A decrease in the forward lean angle and take-off angle would place the body in such a position that would allow the skater to direct as much force horizontally as possible (Kirchner, 1990). Figure 2 illustrates this concept.

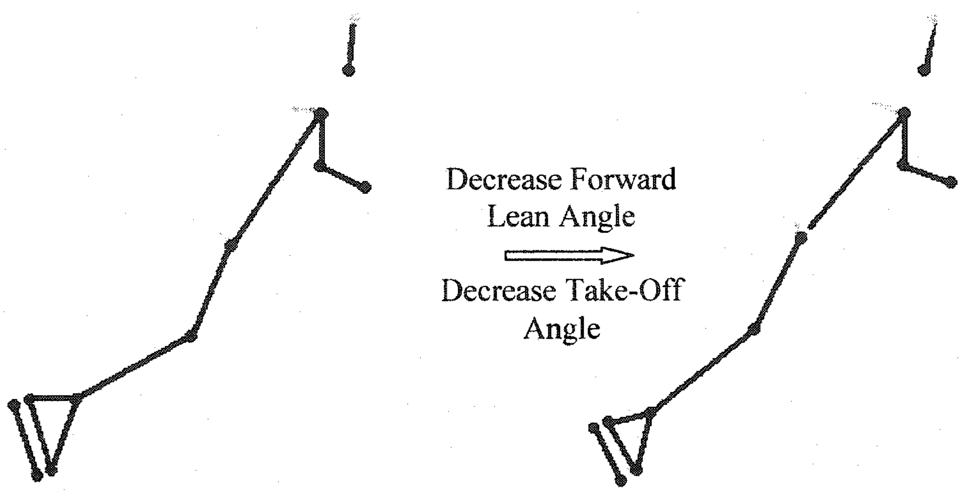

Figure 2. Optimizing horizontal component of force

Table 6 displays the descriptive statistics for the mean forward lean angle at push-off and the mean take-off angle at push-off for the players in the present study as compared to those reported in Purves (2000) and Marino (1983).

Table 6
Forward lean and take-off angles at push-off

	Present Study		Purves (2000)		Marino (1983)
Variable	St.1 ⇒ St.5*	△†	St.1 ⇒ St.5*	△†	$\bar{x} \pm s$
Forward Lean Angle at Push-Off (◦)	49.14 ⇒ 35.65	-13.49	43.31 ⇒ 32.95	-10.36	41.76 ± 7.52
Take-Off Angle at Push-Off (◦)	55.11 ⇒ 51.54	-3.57	53.23 ⇒ 50.30	-2.93	51.67 ± 4.51

* - represents the progression from the first stride to the fifth stride
† - △ represents the change in the parameter from the first to fifth stride

All of the studies have reported similar results, which possibly highlight the dynamic shift from explosive power at the beginning of a start, to progressively less power production over a longer period of force application as the performance progresses. The results suggest that due to fatigue, it would be difficult for an athlete to maintain the same force production throughout every stride, therefore the skating technique has developed to allow for a decrease in force, but still maintain a similar amount of impulse. This could only be true if the time component of impulse were to increase.

It has already been stated that propulsive time increased progressively over the five strides, and by examining the amount of leg extension at push-off, it is possible to determine one possible contributing factor to the time increase. Table 7 displays the descriptive statistics for the mean hip angle at push-off, mean knee angle at push-off, and mean ankle angle at push-off for the players in the present study as compared to those reported in Purves (2000) and Marino (1983).

Table 7
Hip, knee, and ankle angles at push-off

	Present Study		Purves (2000)		Marino (1983)
Variable	St.1 ⇒ St.5*	△†	St.1 ⇒ St.5*	△†	$\bar{x} \pm s$
Hip Angle at Push-Off (◦)	151.83 ⇒ 144.97	-6.86	159.35 ⇒ 142.96	-16.39	155.84 ± 9.75
Knee Angle at Push-Off (◦)	153.13 ⇒ 157.40	4.27	158.05 ⇒ 156.89	-1.16	155.23 ± 13.43
Ankle Angle at Push-Off (◦)	93.77 ⇒ 102.15	8.38	117.09 ⇒ 116.22	-0.87	------ ± ------

* - represents the progression from the first stride to the fifth stride
† - △ represents the change in the parameter from the first to fifth stride

The decreasing trend in the mean hip angle at push-off reported both in the present study and in Purves' study are difficult to interpret due to the nature of the angle definitions as shown in Figure 3.

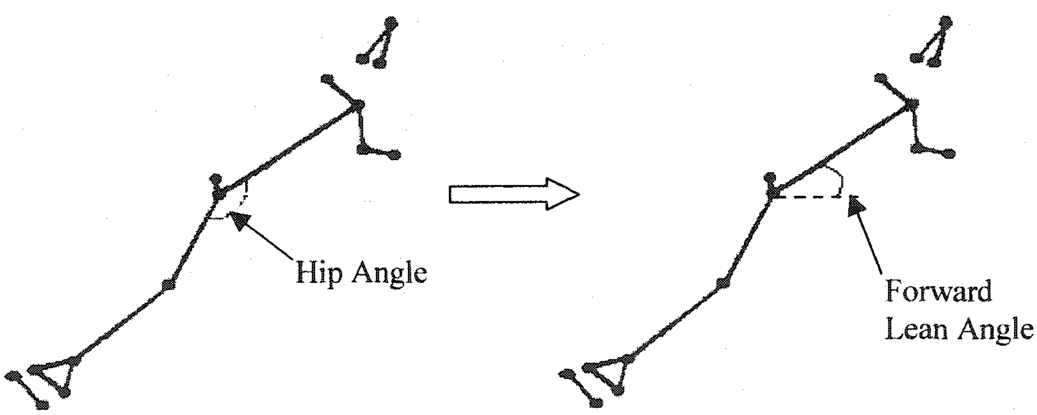

Figure 3. Hip angle and forward lean angle definitions

Hip angle was defined in both studies as the angle between the trunk and thigh. Since forward lean angle is defined as the angle between the trunk and the horizontal, changes in forward lean will affect changes in hip angle. In both studies, forward lean angle at push-off progressively decreased, which would lead to decreases in hip angle, but not necessarily decreases in hip extension. As for mean knee angle and ankle angle at push-off, the present study reports results that are similar in magnitude to those reported by Purves (2000) and Marino (1983), but differ in the direction of change to those reported by Purves (2000). This difference could indicate the variability in technique for development age hockey players, as they lack the physical size, strength, and skill refinement of their NHL prospect counterparts.

In order to develop a full picture of the development age hockey player's skating technique, it is necessary to examine the change in kinematic parameters over the course of a stride. Table 8 displays the descriptive statistics for the mean forward lean angle at touchdown and the mean height of the centre of mass at touchdown for the players in the present study as compared to those reported in Purves (2000) and Marino (1983).

Table 8
Forward lean angle and the height of the centre of mass at touchdown

	Present Study		Purves (2000)		Marino (1983)
Variable	St.1 ⇒ St.5*	$\triangle^{\dagger}$	St.1 ⇒ St.5*	$\triangle^{\dagger}$	$\bar{x} \pm s$
Forward Lean Angle at Touchdown (°)	52.51 ⇒ 45.09	-7.42	52.34 ⇒ 46.56	-5.78	43.44 ± 20.65
Height of the Centre of Mass at Touchdown (m)	0.76 ⇒ 0.73	-0.03	0.91 ⇒ 0.87	-0.04	------ ± ------

* - represents the progression from the first stride to the fifth stride
† - $\triangle$ represents the change in the parameter from the first to fifth stride

All three studies report mean forward lean angles that are similar in magnitude and in the direction of change. When mean forward lean angle at touchdown is examined with the mean height of the centre of mass at touchdown, it can be stated that over the progression from stride one to stride five, the athletes are leaning forward more at touchdown. This decrease would facilitate the increase in the horizontal component of the force applied into the ice that was described earlier.

The range in motion of both the hip and knee would also greatly affect the time of force application. Table 9 displays the descriptive statistics for the mean hip angle at touchdown, mean knee angle at touchdown, and the maximum height of the recovery foot for the players in the present study as compared to those reported in Purves (2000) and Marino (1983).

Table 9
Hip and knee angles at touchdown, and the maximum height of the recovery foot

	Present Study		Purves (2000)		Marino (1983)
Variable	St.1 ⇒ St.5*	△†	St.1 ⇒ St.5*	△†	x̄ ± s
Hip Angle at Touchdown (∘)	97.51 ⇒ 85.21	-12.30	100.79 ⇒ 81.28	-19.51	----- ± -----
Knee Angle at Touchdown (∘)	107.14 ⇒ 101.98	-5.16	107.25 ⇒ 97.21	-10.04	----- ± -----
Maximum Height of the Recovery Foot (∘)	0.10 ⇒ 0.12	0.02	0.20 ⇒ 0.19	-0.01	0.14 ± 0.04

* - represents the progression from the first stride to the fifth stride
† - △ represents the change in the parameter from the first to fifth stride

As with the extension of the hip, the amount of hip flexion is a difficult parameter to interpret due to the affect forward lean angle at touchdown has on the measure. The decrease in mean knee angle at touchdown is directly related to the range in motion of the lower leg. By placing the skate further ahead of the body, a smaller knee angle and hip angle is created, resulting in a greater range of motion to the point of extension, thereby increasing the propulsive time. However, as Marino and Weese (1979) pointed out, propulsion can not occur until the centre of mass has sufficiently moved past the supporting leg, and a kinematic compromise must be reached. In order to increase the range in motion of the legs during skating, gliding must be increased and thereby introducing a deceleration phase. Another indication of this may be explained by the reported a mean vertical displacement of the recovery foot. All three studies report similar findings, with differences attributed to limb length discrepancies. The results of both Purves and the present study demonstrate slight increases in the height achieved by the recovery foot, which may lead to the placement of the recovery foot further forward, and the subsequent decrease in knee angle, and increase in range of motion.

According to Kirchner (1990), skating greatly differs from walking or running in that there is very little friction created between the skate blade and ice in order to provide the necessary resistance to propel against. Therefore, skaters create a propulsive angle between the skate blade and the ice surface in order to create the desired ground reaction force. Kirchner has suggested that the amount of horizontal force generated is directly related to the magnitude of the propulsive angle at push-off, the amount of hip abduction at push-off, and the placement of the recovery skate in a laterally rotated position at touchdown as shown in Figure 4.

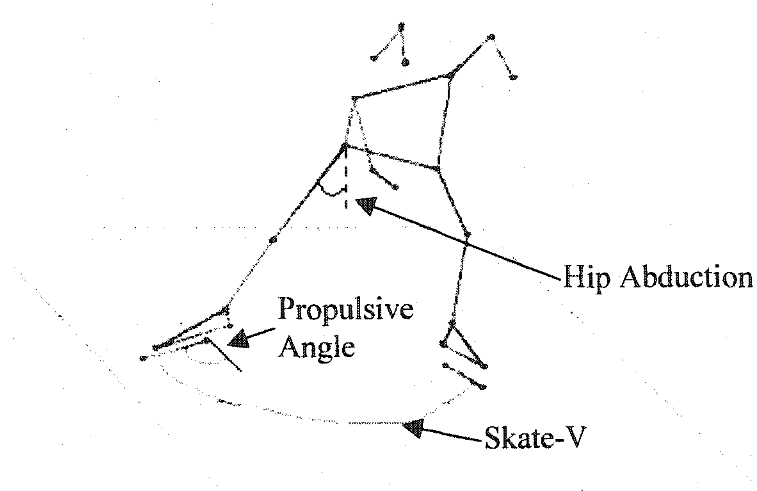

Figure 4. Hip abduction and propulsive angle at push-off, and skate-v at touchdown

Table 10 displays the descriptive statistics for the mean propulsive angle at push-off, mean hip abduction at push-off, and the skate-v at touchdown for the players in the present study as compared to those reported in Purves (2000) and Marino (1983).

Table 10
Propulsive and hip abduction angles at push-off, and the skate-v at touchdwon

Variable	Present Study St.1 ⇒ St.5*	Present Study △[†]	Purves (2000) St.1 ⇒ St.5*	Purves (2000) △[†]	Marino (1983) $\bar{x} \pm s$
Propulsive Angle at Push-Off (∘)	85.54 ⇒ 59.91	-25.63	65.44 ⇒ 53.88	-11.56	40.54 ± 6.20
Hip Abduction at Push-Off (∘)	25.55 ⇒ 23.92	-1.63	5.93 ⇒ 16.75	10.82	----- ± -----
Skate-V at Touchdown (∘)	85.10 ⇒ 49.73	-35.37	108.51 ⇒ 77.02	-31.49	----- ± -----

* - represents the progression from the first stride to the fifth stride
[†] - △ represents the change in the parameter from the first to fifth stride

There is quite a bit of discrepancy between all three studies with respect to the above measures, largely due to the definition of the parameters. Although propulsive angle at push-off and skate-v at touchdown were defined the same in Purves' study, the present study used projected segmental angles unique to the Peak Motus software in order to eliminate the differences in height between segments. In traditional three-dimensional video analysis, the angle between two segments is calculated regardless of their relative position in space. A procedure such as this introduces error in the angle calculation derived from the direct linear transform of the two-dimensional images. By using a projected angle, the computer radiates an angle from the highest point, down to the lowest point, thereby creating an angle calculation between two segments projected onto a common plane. As well, Purves defined hip abduction as the angle between the thigh and the YZ plane, whereas in the present study, hip abduction was defined as the angle between the thigh and the XY plane.

Nevertheless, the results from the present study indicate that the propulsive angle at push-off, and lateral rotation of the recovery foot at touchdown decreased, along with a decrease in hip abduction at push-off as skating velocity increased. de Koning et al. (1995) reported that speed skaters used large propulsive angles to push-off at the start, which progressively decreased as skating velocity increased. The propulsive angle is large at the start, in order for there to be sufficient resistance created between the skate blade and ice surface. Propulsive angle then starts to decrease, thereby limiting the amount of extension of the lower leg, and decreasing the rate of muscular contraction. There is a biomechanical trade-off as the rate of muscular contraction allows the skater to generate greater strength during the muscle contraction. In order to continuously generate large forces into the ice surface at push-off, the skate blade must be progressively positioned in a decreasing angle away from the direction of travel. The decrease in propulsive angle is accompanied by an increase in hip abduction in order to continuously generate large propulsive forces. This discussion was supported by Purves (2000). The relatively large mean propulsive angle and decrease in hip abduction observed in the present study suggests a reliance for the development aged hockey players on force production, rather than on the quality of their technique. For development age skaters, technique has not reached a high level of refinement, and therefore improvements in maximum velocity are governed by increases in force production. This result favours those players with a greater physical size, as production of force is directly proportional to the body mass.

The motion of the arms in the present study was extremely variable across the participants. Although all of the players were instructed to only place one hand on the stick, the children's movements were inconsistent. As a result, some players placed one hand on the stick, and others placed two. As well, some players would change between a single and double grip mid-way through the trial. There needs to be more restrictions and better instructions provided to young athletes in order to better assess the role of the upper body in skating technique.

In summary, the results of the analysis of skating technique for the present sample suggest that development age skaters begin with fast, short strides, that lead to longer strides covering a larger range in motion of the leg, with increased double support and propulsive times. Players in the present study tended to start in a more upright position. As the player's velocity increased, the amount of forward lean and leg extension also increased. The height of the recovery foot increased slightly in order to accommodate the wider range in motion developed over the progression from stride one to stride five. The hip was laterally rotated at touchdown, creating a propulsive angle with the ice that gradually decreased as velocity increased. The amount of hip abduction and lateral rotation also decreased progressively from the start to the completion of five strides as a result of the increasing velocity. This description of the acceleration phase in development age hockey players supports that of Chambers (1989), and is illustrated in Figure 5.

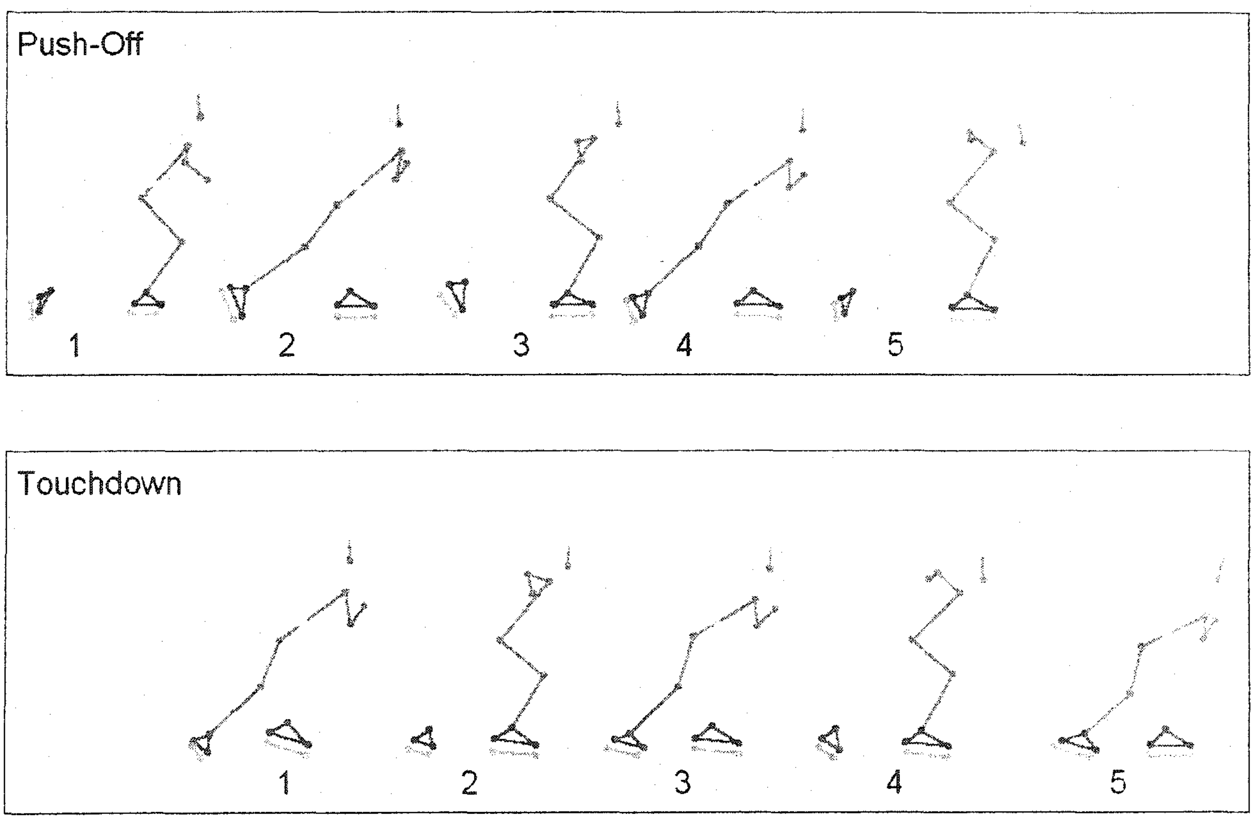

Figure 5. Skating sequence divided into the critical events of push-off and touchdown

A Comparison of Development Age Skating Technique vs. Elite Adult Skating Technique

The graphs of the mean values for kinematic parameters reported in Purves (2000) and the present study were compared in order to assess the differences in skating technique between elite and novice ice skaters during the acceleration phase of a forward start.

Angle angle. Figure 6 displays a plot for the mean ankle angle at push-off for both the development age players, as well as the elite players.

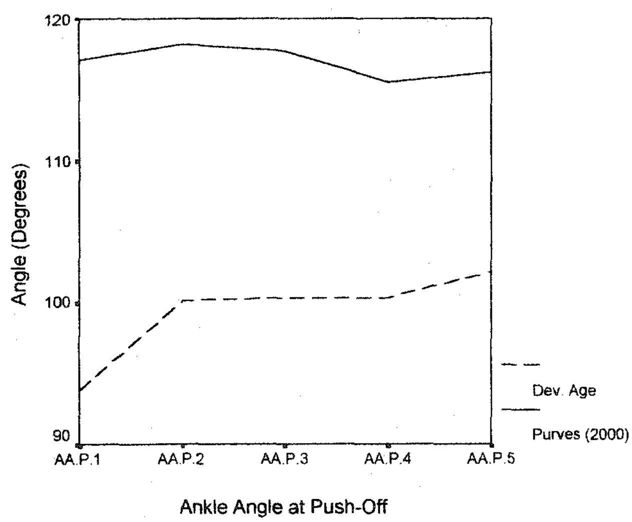

Figure 6. Mean ankle angle at push-off

The difference between the mean ankle angle at push-off for development age players and elite players was the magnitude of the angle. The elite players were able to create a much greater amount of plantar flexion at push-off throughout the progression from stride one to stride five. On average, the elite players created 17.59 degrees more plantar flexion of the ankle at push-off. Kirchner (1990) identified that by pushing the toe further away from the direction of travel at push-off, a greater horizontal impulse is created which results in a greater horizontal velocity. Kirchner discussed the way in which the development of the hockey skate boot contributed to the provision of ankle support and Achilles tendon protection without regard for the effect a more rigid boot can have on performance. The results of this study suggest that development age hockey players are unable to generate sufficient plantar flexion at push-off, quite possibly due to an inability to generate enough muscular force to overcome the stiffness of the hockey skate boot.

Double support time, propulsive time, and stride length. As previously stated, rapid acceleration is characterized by quick and short strides, which result in the creation of a flight phase and the subsequent elimination of double support. A plot for the mean double support times across strides one through five for the present study and Purves (2000) is presented in Figure 7.

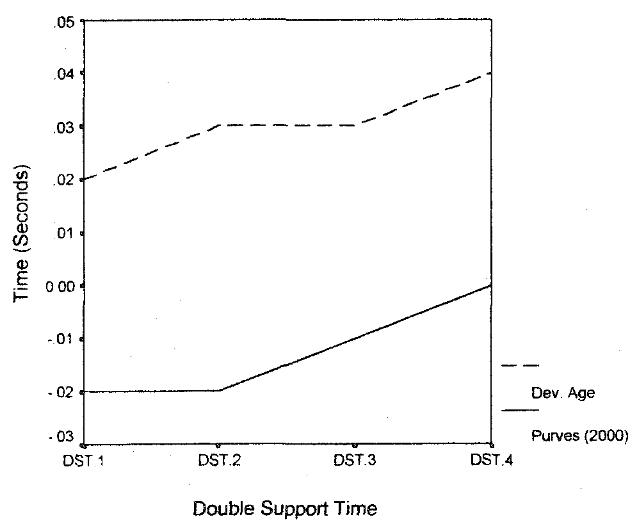

Figure 7. Mean double support time

On average, the athletes in Purves' study had a negative double support time during the first five strides which indicates a flight phase. However, the length of flight time did decrease, indicated by a positive change over time. Similarly, the development age hockey players in the present study had a double support phase that consistently increased in length. Although the direction of change between the two groups was the same, the magnitude was different. The difference in magnitude can be explained as Marino and Dillman (1976) stated that at higher rates of acceleration, no double support phase was demonstrated. The quicker and shorter strides utilized by the elite athletes are also highlighted in Figures 8 and 9.

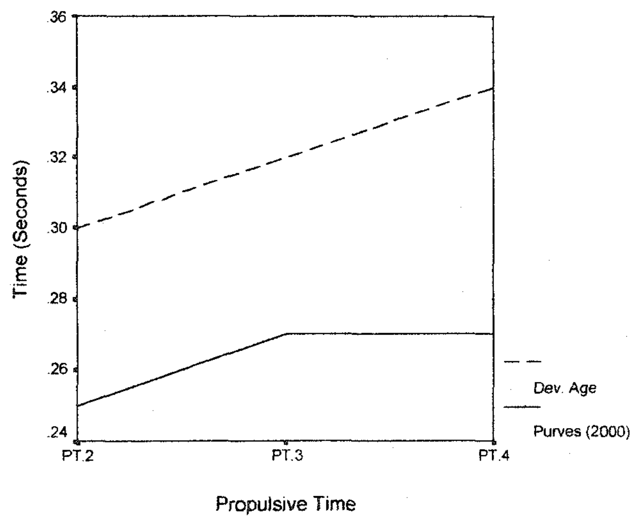

Figure 8. Mean propulsive time

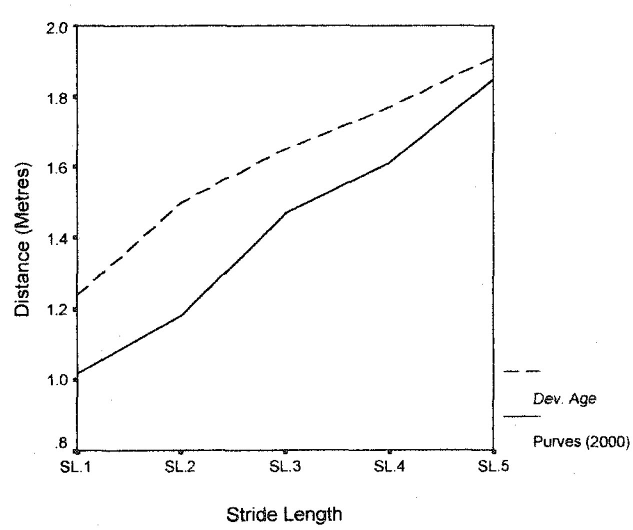

Figure 9. Mean stride length

These graphs represent the mean propulsive time and the mean stride length respectively. Again, as with double support time, the direction of change in mean propulsive time and mean stride length over the performance is the same between the two groups. The faster, shorter strides utilized by the elite athletes in Purves (2000) resulted in consistently lower values as compared to the development age players. All of the measures of stride rate further support the findings from the mean ankle angle in that there is a difference between the two groups with respect to the magnitude of selected kinematic parameters that are possibly a function of size and strength.

Forward lean angle, hip angle, and knee angle. The following table lists the range of the absolute difference between the mean values from both studies, along with the respective mean and standard deviation of the difference.

Table 11:
Absolute difference between mean values

Variable	Minimum	Maximum	Mean	Standard Deviation
Forward Lean Angle at Push-Off	1.89	5.83	4.26	1.84
Forward Lean Angle at Touchdown	0.17	6.78	3.23	2.65
Hip Angle at Push-Off	2.01	7.52	4.86	2.55
Hip Angle at Touchdown	2.79	9.80	5.38	2.98
Knee Angle at Push-Off	0.40	4.92	1.90	1.91
Knee Angle at Touchdown	0.11	4.71	1.75	2.13

There is little difference in magnitude between the two skill levels on all six variables, indicating that there must be some other factor demonstrating the progression in skill acquisition. The mean forward lean angle at push-off and touchdown, mean hip angle at push-off and touchdown, and mean knee angle at push-off and touchdown are all presented in Figures 10, 11, 12, 13, 14, and 15 respectively.

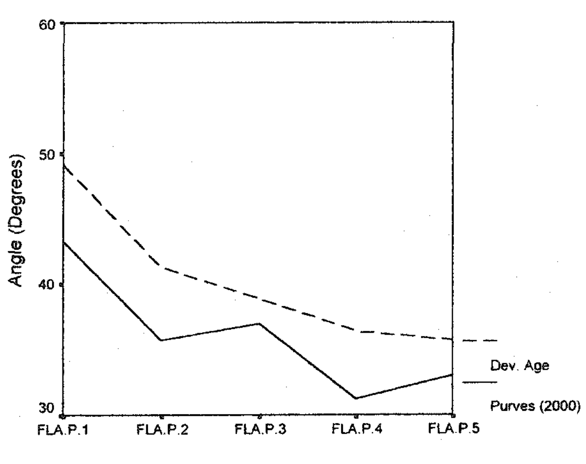

Figure 10. Mean forward lean angle at push-off

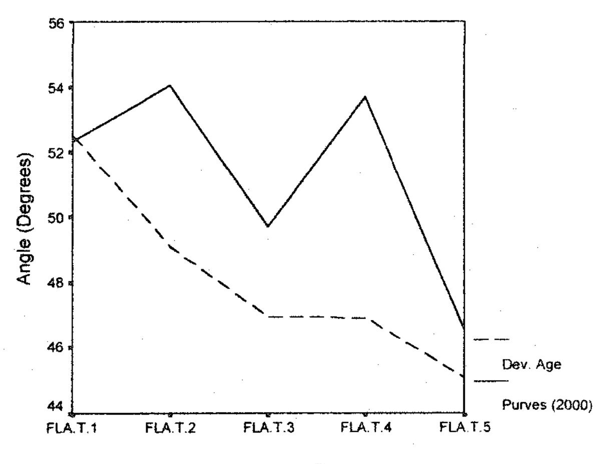

Figure 11. Mean forward lean angle at touchdown

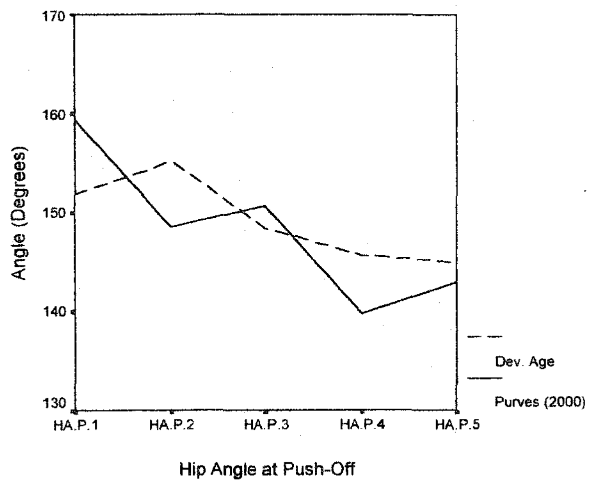

Figure 12. Mean hip angle at push-off

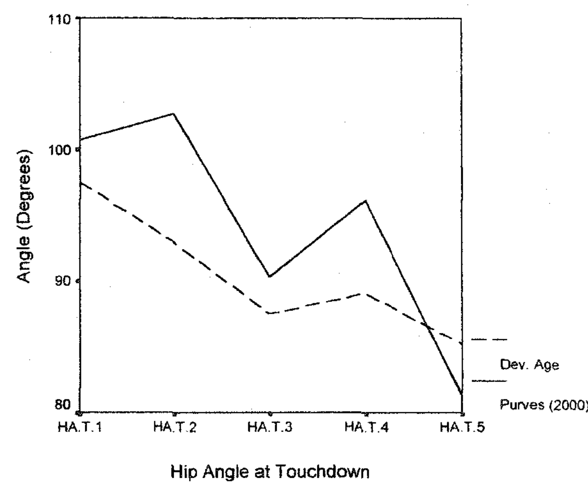

Figure 13. Mean hip angle at touchdown

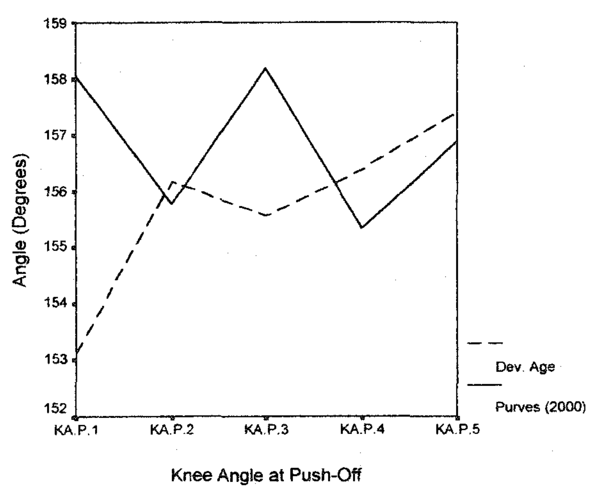

Figure 14. Mean knee angle at push-off

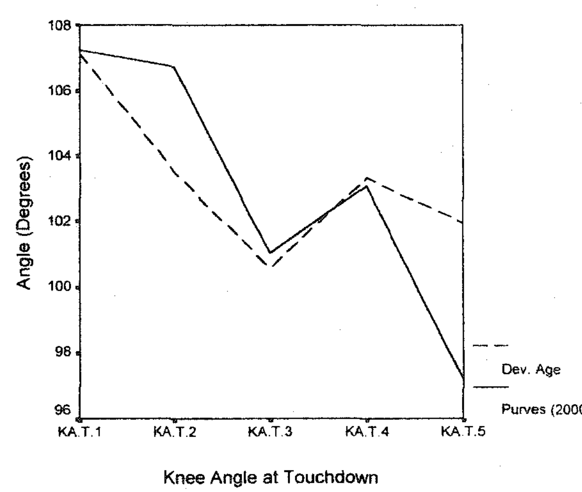

Figure 15. Mean knee angle at touchdown

All six graphs display similar changes in direction, relatively similar mean values, but patterns that are strikingly different. The development age players elicited a pattern that appears to be more linear, without any consistent changes in the magnitude of the mean joint angles. However, the elite players consistently displayed magnitudes that would alternately increase and decrease over the progression from stride one to stride five. This pattern appears to indicate that the elite players performed the skating task differently on one side of the body as compared to the other. As there has been no literature found that explores the relative difference between dominant and non-dominant sides in forward skating, for the purpose of the following explanation, the dominant side will be defined as the side that initiates the first push-off. In both of the studies being compared, the dominant side would be captured at the first, third, and fifth instants in time, whereas the non-dominant side would be captured at the second and fourth instants in time. When each side was examined separately, an identical rate of change was observed, but at a different level of flexion or extension. The pattern suggests that as players get older and progress through the acquisition of skating skill, a preferred or dominant side is favoured for the production of force. However, more research needs to be carried out in order to assess the impact of favouring a dominant side has on performance before conclusions regarding the mature pattern can be drawn.

Height of the centre of mass and take-off angle. The next graph reported in Figure 16 represents a comparison of the mean height of the centre of mass at touchdown.

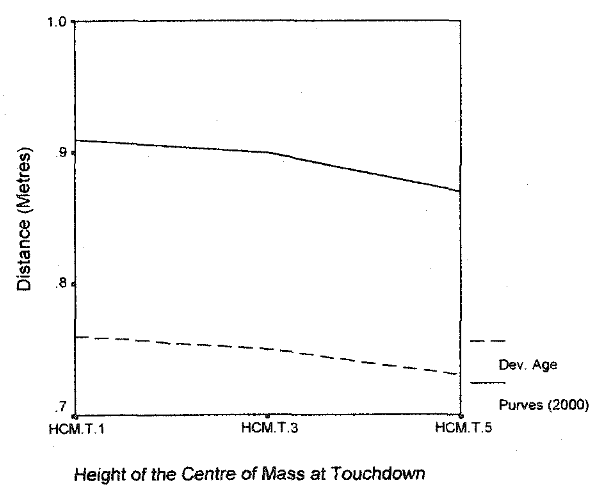

Figure 16. Mean height of centre of mass at touchdown

The differences observed between the development age and the elite hockey players with respect to the change in mean height of the centre of mass can be explained by the differences in player size. The athletes in Purves' study had a mean standing height of 187.00 ± 5.00 cm, whereas the athletes in the present study had a mean standing height of 145.12 ± 6.39 cm. Therefore, the mean height of the centre of mass for the elite players was consistently greater in magnitude.

Figure 17 displays a comparison between the two studies with respect to mean take-off angle at push-off.

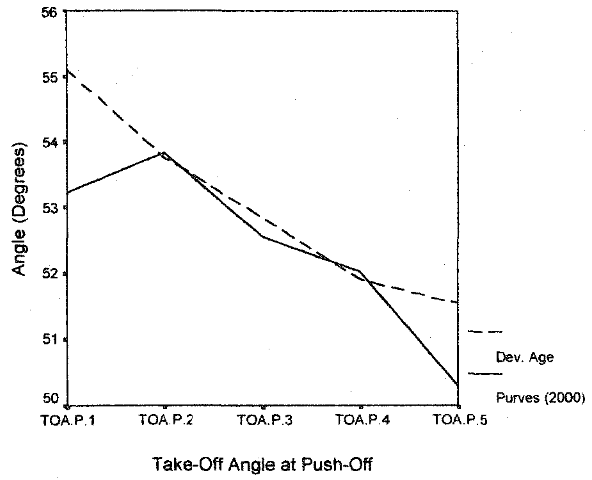

Figure 17. Mean take-off angle at push-off

In both studies, take-off angle was defined as the angle above the horizontal of a line from the toe of the boot to the hip, as shown in Figure 18.

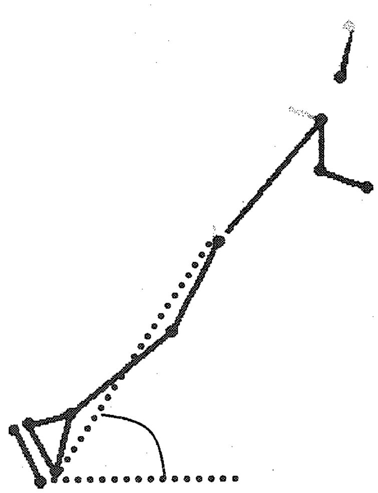

Figure 18. Take-off angle at push-off definition

This value provides a measure of how much of the force being applied into the ice surface is directed in the horizontal plane. To a lesser extent, the elite players again displayed an indication of a dominant/non-dominant side relationship. However, the comparison between the two groups with respect to the first and the last take-off angles is most interesting. The development age players had a mean take-off angle that was 1.88 degrees less at the first push-off, which could result in 4.65% less force being directed horizontal. As well, at the fifth push-off, the elite players had a mean take-off angle that was 1.24 degrees less than the development age hockey players. This difference would result in a loss of only 2.61% of the horizontal component. In a skill that relies on the optimal production of horizontal force, the development age players in the present study were unable to generate as great of an impulse at the start as the elite players were.

In summary, the development age hockey players in this study were very similar to their elite adult counterparts in skating patterns with respect to stride characteristics. The differences that were observed were attributed to the differences in size and strength. It was interesting to find that the more advanced athletes showed similar signs of dominant and non-dominant skating strides.

Bivariate Correlations and Regression Analyses

Using SPSSS 10.0 for Windows, nine independent samples t-tests were used to determine the significance of the difference between the two skill levels with respect to time to skate six metres, delay time, height, weight, average horizontal velocity over five strides, and between position played with respect to time to skate six metres, height, weight, and average horizontal velocity over five strides. The results from all nine tests are presented in Appendices G and H. As a result of no significant findings on all nine independent samples t-tests, the sample of players tested in the present study was considered to be a homogenous sample.

All of the kinematic parameters were entered into a bivariate correlation matrix with time to skate six metres using SPSS 10.0 for Windows. The results revealed that the following 23 variables were significantly correlated with time to skate six metres at $p<0.05$.

Table 12
Significant correlations with time to skate six metres

Variable*†	N	R	p
Hip Angle-t5	30	0.399	0.029
Forward Lean Angle-p4	30	0.459	0.011
Knee Angle-p2	30	-0.375	0.041
Knee Angle-t2	30	0.405	0.026
Knee Angle-t4	30	0.364	0.048
Knee Angle-t5	30	0.367	0.046
Take-Off Angle-p1	30	0.468	0.009
Take-Off Angle-p2	30	0.585	0.001
Take-Off Angle-p3	30	0.538	0.002
Take-Off Angle-p4	30	0.491	0.006
Take-Off Angle-p5	30	0.432	0.017
Hip Abduction-p2	30	-0.445	0.014
Height of the Centre of Mass-t5	30	0.382	0.037
Stride Length-1	30	-0.582	0.001
Stride Length-2	30	-0.640	0.000
Stride Length-3	30	-0.513	0.004
Stride Length-4	30	-0.623	0.000
Stride Length-5	30	-0.543	0.002
Maximum Height of the Recovery Foot-4	30	-0.381	0.038
Range in Motion of the Knee-1	30	0.460	0.011
Range in Motion of the Knee-2	30	0.543	0.002
Range in Motion of the Knee-3	30	0.407	0.026
Range in Motion of the Forward Lean Angle-3	30	-0.548	0.002

* - measures taken at the event of push-off are denoted with –p#
† - measures taken at the event of touchdown are denoted with –t#

The complete list of correlations is presented in Appendix I.

Once average horizontal velocity over five strides was calculated, all of the kinematic parameters were entered into a bivariate correlation matrix using SPSS 10.0 for Windows. The results revealed that the following 32 variables were all significantly correlated with average horizontal velocity over five strides at $p<0.05$.

Table 13
Significant correlations with average horizontal velocity over five strides

Variable*[†]	N	r	p
Propulsive Time-2	30	0.365	0.047
Hip Angle-p1	30	0.453	0.012
Hip Angle-t5	30	0.393	0.032
Forward Lean Angle-p4	30	-0.413	0.023
Knee Angle-p1	30	0.533	0.002
Knee Angle-p2	30	-0.375	0.041
Knee Angle-t1	30	-0.402	0.028
Knee Angle-t2	30	-0.374	0.042
Knee Angle-t4	30	-0.401	0.028
Knee Angle-t5	30	-0.412	0.024
Take-Off Angle-p1	30	-0.613	0.000
Take-Off Angle-p2	30	-0.657	0.000
Take-Off Angle-p3	30	-0.564	0.001
Take-Off Angle-p4	30	-0.508	0.004
Take-Off Angle-p5	30	-0.445	0.014
Hip Abduction-p1	30	0.418	0.022
Hip Abduction-p2	30	0.523	0.003
Hip Abduction-p5	30	0.409	0.025
Skate-V-t5	30	-0.438	0.016
Height of the Centre of Mass-t5	30	-0.374	0.042
Shoulder Abduction-p2	30	-0.476	0.008
Stride Length-1	30	0.744	0.000
Stride Length-2	30	0.731	0.000
Stride Length-3	30	0.547	0.002
Stride Length-4	30	0.586	0.001
Stride Length-5	30	0.391	0.032
Maximum Height of the Recovery Foot-4	30	0.631	0.000
Range in Motion of the Hip-3	30	-0.374	0.042
Range in Motion of the Knee-1	30	-0.462	0.010
Range in Motion of the Knee-2	30	-0.489	0.006
Range in Motion of the Knee-3	30	-0.400	0.028
Range in Motion of the Forward Lean Angle-2	30	-0.505	0.004

* - measures taken at the event of push-off are denoted with –p#
[†] - measures taken at the event of touchdown are denoted with –t#

The complete list of correlations is presented in Appendix J.

A backward stepwise regression analysis was used to identify the variables that best predicted the time to skate six metres. The thirty-two variables that were determined to correlate significantly with both time to skate six metres and average horizontal velocity were entered into the analysis along with the variables height and weight. Four variables were eliminated from the second model, and the stepwise regression was terminated, as the change in R squared was not significant at $p < 0.05$. The remaining 28 variables accounted for 100% of the variance in time to skate six metres. A summary of the model is presented in Appendix K: Table K1. The set of predictors was comprised of variables in series (e.g. knee angle at push-off strides 1 to 4) as well as variables representing single events (e.g. maximum height of recovery foot at stride 4). When the predictor was comprised of two variables in series the slope of the line between the variables was used to represent the composite of the progression. A log-log transformation of the power function was used to transpose the raw scores for the strides that occurred in series within the variable set into a single composite score (Stevens, 1957).

Finally, the six transformed variables and the 12 variables that occurred as single events were entered into a backward stepwise multiple regression in order to develop a structural equation of predictors for time to skate six metres. The variables that best predict time to skate six metres are presented in Equation 4, below.

Equation 4. Regression equation for time to skate six metres

$$y_i = 1.283 + 0.0004x_1 + 0.007\,x_2 - 0.246\,x_3 - 0.005\,x_4 - 0.008\,x_5 + 0.006\,x_6$$

where: x_1 = transformed variable (knee angle at push-off 1,2)
x_2 = knee angle at touch down 1
x_3 = transformed variable (take-off angle at push-off 1,2, 3)
x_4 = hip abduction angle at push-off 5
x_5 = the range of motion of the forward lean angle 2
x_6 = player weight

Equation 4 was the 13th model, was significant at $p<0.001$, and it accounted for 61.4% of the variance in time to skate six metres. A summary of the model is presented in Appendix K: Table K2.

The kinematic parameters identified in the regression equation were directly related to the amount of horizontal impulse applied into the ice surface. de Koning et al. (1995) reported that larger ranges in motion of the hip and knee result in greater extension velocities, and therefore a greater force application. The positive coefficient for the transformed variable of the knee angle at push-off for strides one and two supports de Koning et al. (1995) and indicates the importance of an increase in the amount of knee extension during the first two strides. In addition, there was an increase in the knee angle at touchdown, which increased the range in motion of the joint during push-off. Purves (2000) and de Koning et al. (1995) reported that as skating velocity increased, the amount of hip abduction must also increase in order to maintain a sufficient propulsive angle. Although Purves (2000) stated that there is no published literature that has identified optimal ranges in hip abduction throughout the ice skating stride, a mean hip abduction angle range of 5.93 ± 3.43 degrees for stride one to 16.75 ± 3.78 degrees for stride five was reported. In comparison, the results of the present study demonstrated a mean hip abduction range of 25.55 ± 7.08 degrees for stride one to 23.92 ± 6.38 degrees for stride five. The reported range for development age hockey players was considerably greater than those reported for elite athletes, especially at the start of the skill progression. The observed increase in the hip abduction angle may place the leg in such a position that stride rate is compromised by the range in motion of the driving leg. It may be necessary for development age hockey players to decrease the amount of hip abduction at the beginning of the performance in order to allow for an optimal range of motion. In the results of the regression analysis of the present study, unlike the previous work of Marino (1983) and Purves (2000), measures of stride characteristic (stride rate, stride length, and propulsive time) were not identified while weight was included. By comparing the three structural models, the importance of body size on skating performance has been identified.

The Effect of Body Size on Skating Technique Assessment

Frequency tables of birth dates across quartiles for both levels of play are presented below.

Table 14
Frequency distribution chart of birth dates for players selected into representative hockey

Quartile	Tally	Frequency	Relative Frequency	Cumulative Frequency
1	||||	4	0.24	29%
2	||||| |	6	0.35	59%
3	|||||	5	0.29	88%
4	||	2	0.12	100%
		n = 17	total p = 1.00	

Table 15
Frequency distribution chart of birth dates for players selected out of representative hockey

Quartile	Tally	Frequency	Relative Frequency	Cumulative Frequency
1	||||	4	0.31	31%
2	||||	4	0.31	62%
3	|||	3	0.23	85%
4	||	2	0.15	100%
		n = 13	total p = 1.00	

The relative age effect could not be evaluated in this study because the sample size was comprised of 30 participants with only 17 drawn from "representative level hockey". As a result, the number of individuals born in each quartile of the year was insufficient for statistical analyses. When Barnsley et al. (1985) identified a relative age effect, all of the birth dates for players competing in the NHL, OHL, and WHL were used. Similarly, Barnsley and Thompson (1988) had access to all of the birth dates for the Edmonton Minor Hockey Association, Boucher and Mutimer (1994) had access to all of the birth dates for hockey players competing in Nova Scotia and the NHL, and Montelpare et al. (1996) utilized all of the birth dates for the 1995-1996 season in the CIAU, OHL, NHL, and MHAC. At the time of the present study, the complete list of birth dates for all players currently competing in the PAMHA were not made available to the researcher. However, using the results from the present study, it is possible to attempt to hypothesize the impact body size, and consequently the relative age effect, has on the assessment of skating technique.

There are similarities in the identification of stride characteristics as significant predictors of time to skate six metres when the structural models developed by Marino (1983) and Purves (2000) are compared. Marino (1983) reported that stride rate was one of four predictors, whereas Purves (2000) reported that stride length and propulsive time were two of nine predictors. As previously discussed, these measures of stride characteristics are representative of the amount of power generated during propulsion. In addition, Purves (2000) also measured and identified peak anaerobic power as a significant predictor of time to skate six metres. The similarities between the two studies highlight and support Allinger and Van den Bogert's (1997) theory that instantaneous power can greatly affect the outcome in skating tasks. Considering that Rahkila and colleagues (1998) determined that maturationally advanced hockey players at the age of nine have a greater stature, larger relative weight, and greater grip strength, it becomes clear that selecting players based on the outcome of a speed skating task could favour those players born earlier in the calendar year. Furthermore, the present study identified player weight as a significant predictor of time to skate six metres. Players that have a larger relative weight also have a physical advantage in the production of power during propulsion. The relationship between physical size and instantaneous power production could affect the selection of players to elite levels of hockey prior to puberty.

Summary

The two questions which were central to the present study were:

1. What are the biomechanical characteristics of minor hockey players while performing an on-ice acceleration skill test?
2. What is the contribution of height and weight on the assessment of skating technique?

The results of the comparison of kinematic data between studies indicated a difference between development age, varsity, and elite adult hockey players with respect to the magnitude of selected kinematic parameters that are largely a function of size and strength. Furthermore, the analysis of skating technique for the present sample was consistent with current coaching literature. When a predictive equation was created, it was found that the following six variables best predicted time to skate six metres (in no particular order):

1) knee angle at push-off 1,2

2) knee angle at touch down 1

3) take-off angle at push-off 1,2, 3

4) hip abduction angle at push-off 5

5) the range of motion of the forward lean angle 2

6) player weight

The parameters identified in the predictive equation were directly related to the amount of horizontal impulse applied into the ice surface. Overall, the development age hockey players in this study were very similar to their elite adult counterparts in skating patterns with respect to stride characteristics. The differences that were observed were attributed to the differences in size and strength. Comparing structural models across studies further suggests the importance of body size on skating performance.

In addition to the reported findings of the present study, a number of issues for future research were identified. A standard definition of time to completion must be created. The present study began timing the participant's performance from the start of forward motion after the "Start" command. It is unclear if the other studies used for comparison defined the start of the performance the same, or if timing began with the first push-off. The actual starting point on the ice surface needs to be clearly marked and strictly enforced during testing. In the present study, it was found that some participants would move their feet off of the start point after they had been instructed where to begin. Pylons on either side of the start location delimited the point of interest, however an identifying marker that is physically placed at the exact starting point may help alleviate this problem. Along with this, the body position that the participants start from and the position of the stick must be kept consistent. In the present study, it was found that some players preferred a one-handed grip, while others preferred a two-handed grip. The grip each participant uses should be kept consistent in order to better evaluate the contribution of the upper body during acceleration. Furthermore, future research should define what equipment is to be used by the participant during testing. The present study had the players dressed only in their hockey skates, and holding a hockey stick. Wearing a hockey helmet was optional. Upon review of previous research, it was unclear what equipment the participants were wearing during testing. The amount and type of equipment used could greatly affect the performance, and therefore should be standardized. However, all of the afore mentioned problems could be solved through direct and explicit instructions to the participants.

Conclusions

The results of the present study have contributed to our understanding of the biomechanical characteristics of development age hockey players with respect to skating technique and the prediction of on-ice acceleration. The use of a bivariate correlation matrix, followed by a two step backward stepwise regression analysis involving the transpose of raw scores into composite scores through a log-log transformation of the power function has been shown to be effective in the identification of kinematic parameters for the purpose of predicting time to skate six metres. Consistent with the finding of Purves (2000), the use of three-dimensional pan and tilt video analysis in the present study has enabled the researcher to measure more precisely the kinematic parameters of forward acceleration. Furthermore, the results obtained in the present study contribute to the body of literature which describes skating technique.

Finally, the potential confounding effects of size and weight on the evaluation of the quality of skating performances have been proposed and discussed. It is particularly important to note that the range of variability in skating performance between the elite and development age hockey players suggest the need for further research.

Recommendations

The following are recommendations for future research in the kinematic analysis of the forward ice-skating skill.

1) A standardized starting position should be developed.
2) A more detailed analysis of the upper body during acceleration is required.
3) The use of three-dimensional video analysis for an examination of various other ice-skating skills, such as forward steady state skating, and skating backwards is recommended.
4) A standardized definition of time to completion should be developed.
5) Further research needs to be conducted in order to assess the existence of a dominant and non-dominant skating stride pattern, and the effect it has on technique.
6) There is also a need to investigate if a dominant and non-dominant pattern exists in other cyclical activities such as walking, running, cycling, etc..

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Appendix A: Cover Letter

The Biomechanical Characteristics of Development Age Hockey Players: Determining the Confounding Effects of Body Size on the Assessment of Skating Technique

Dear Parent/Guardian:

I am interested in identifying the biomechanical characteristics of house league and representative minor hockey players. Currently, young hockey players are selected to the representative teams based primarily on height, weight, and other physical attributes. Previous research has shown that a relative age effect exists within the elite or representative levels of each league, but not within the recreational or house leagues. The term relative age effect refers to the difference in biological and chronological age between children in the same age grouping that results from different birth dates within the same birth year. Considering the range of variability for the height and weight of 10 year old children, it may be inappropriate to base player selection on these two measures. I hope to be able to determine a template of skating technique based on technical abilities and potential, rather than on size.

In order to assess your child's skating technique, he or she will be required to complete an on-ice acceleration skill test. This test is based upon guidelines that have been created through previous research, and it only requires your child to perform as they would in any other hockey related activity. As well, you along with your child, will be required to complete a player profile questionnaire that will provide all of the necessary supplemental information for this study. A player technique profile, which includes a summary of the critical measurements along with graphical displays, will be developed and distributed to all of the participants at the end of the summer when the video analysis is completed.

The videography procedure will take approximately 30 minutes and will be conducted at the Thunder Bay Tournament Centre. All information gathered during the assessment will remain confidential and securely stored at Lakehead University for seven years. You may obtain a final copy of the results through the University Library by August 30, 2002.

Thank-you for your cooperation. Should you require any additional information please do not hesitate to contact me.

Sincerely,

Allan T. Wrigley, H.B.K.,
Graduate Student, School of Kinesiology,
Lakehead University,
Thunder Bay, Ontario, P7B 5E1
allan_wrigley@yahoo.com

Appendix B: Letter of Informed Consent

My signature on this form indicates that my son or daughter will participate in a study by Allan Wrigley on "The Biomechanical Characteristics of Development Age Hockey Players: Determining the Confounding Effects of Body Size on the Assessment of Skating Technique".

I have received an explanation about the nature of the study and its purpose. I understand that my son or daughter's participation in this study is voluntary, and that he or she may withdraw from this study at any time and for any reason, without any reprisal to my child. Further, I understand that participation in this study does not involve any risks beyond those normal to ice skating.

I understand that all data will be kept strictly confidential and only Allan Wrigley, and his research associates will have access to the data. Once entered into the database, there will be no way to identify my child directly within the large set of data reported. The data will be stored for seven years according to University Policy. I may obtain a final copy of the results through the University Library by August 30, 2002.

Signature of Parent/Guardian: ______________________________ Date: ________________

Appendix C: Player Profile Form

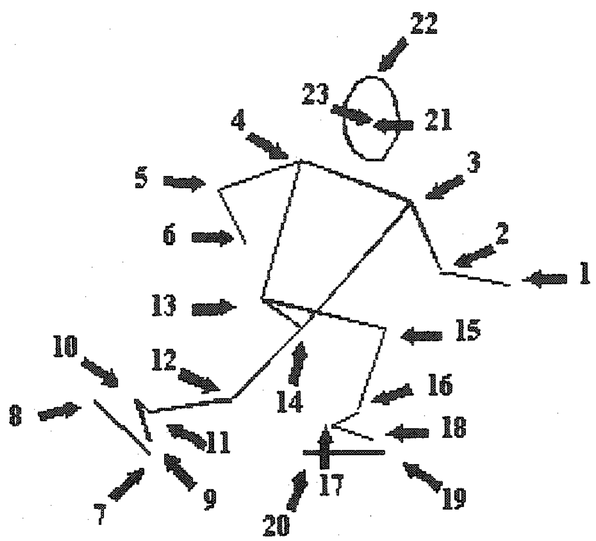
Player Profile

Name: ______________________ Age: _____ Position: ______________

Height: ________ Weight: ________ Birth Day, Month, & Year: __________

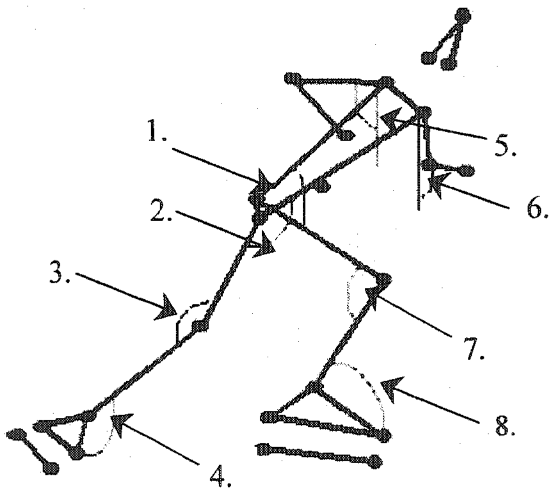
Team Name: ____________________ League Name: ____________________

Appendix D: 23-Point Spatial Model



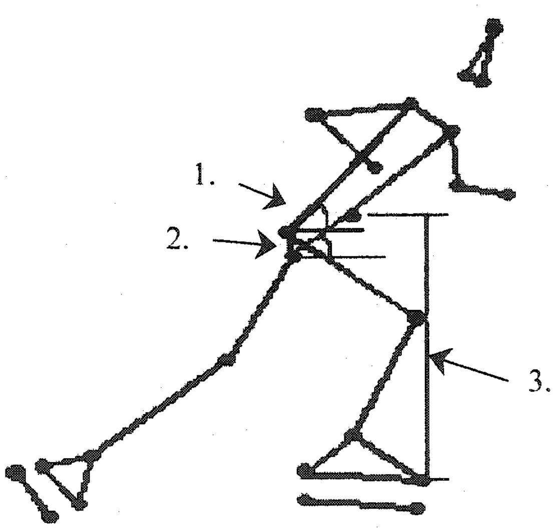
1. right wrist
2. right elbow
3. right shoulder
4. left shoulder
5. left elbow
6. left wrist
7. right skate tip
8. right skate heel
9. right toe
10. right heel
11. right ankle
12. right knee
13. right hip
14. left hip
15. left knee
16. left ankle
17. left heel
18. left toe
19. left skate tip
20. left skate heel
21. left ear
22. top of head
23. right ear

Appendix E: Kinematic Variables of Interest



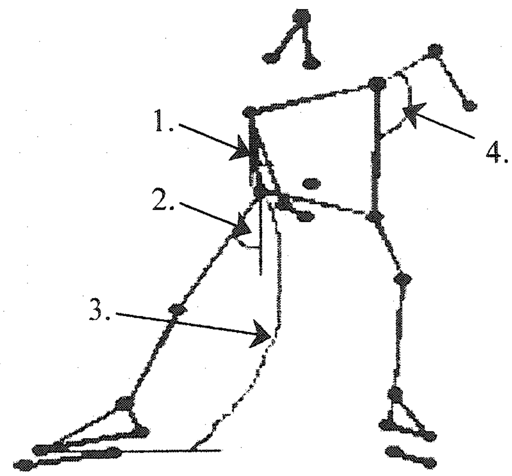
1. hip angle at touch down
2. hip angle at push off
3. knee angle at push off
4. ankle angle at push off
5. shoulder flexion / extension at touch down
6. shoulder flexion / extension at push off
7. knee angle at touch down
8. ankle angle at touch down

Figure E1. Side view #1



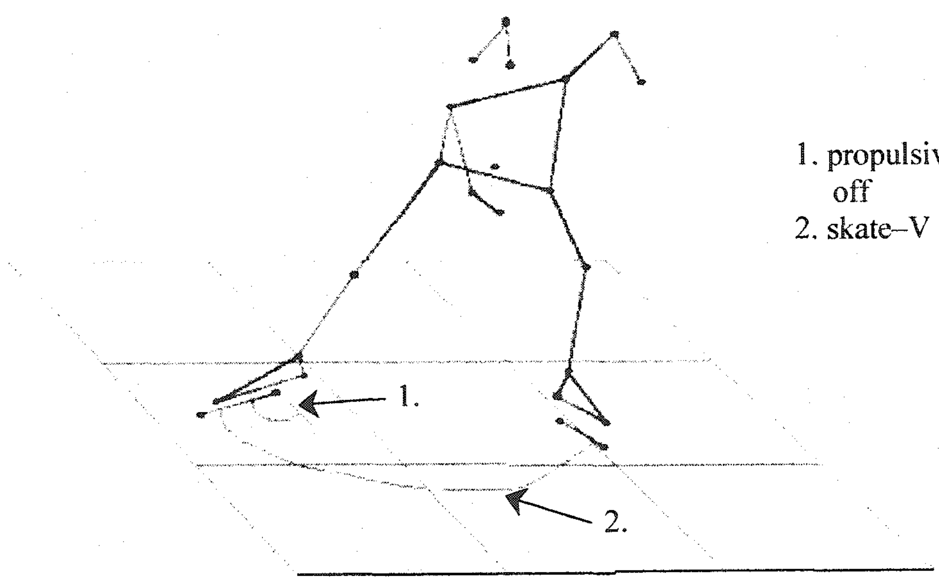
1. forward lean angle at touch down
2. forward lean angle at push-off
3. height of the centre of mass at touch down

Figure E2. Side view #2



1. shoulder abduction/ adduction at push-off
2. hip abduction at push-off
3. take off angle at push-off
4. shoulder abduction/ adduction at touch down

Figure E3. Front view



1. propulsive angle at push off
2. skate–V at touch down

Figure E4. Front view of projected angles

Appendix F: Descriptive Statistics

Variable		N	Min.	Max.	Mean	Std. Dev.	Skewnes	Kurtosis
Height (cm)		30	129.54	160.02	145.12	6.39	-0.13	0.25
Weight (kg)		30	27.27	50.00	36.09	6.49	0.89	0.02
Birth Month		30	1.00	10.00	5.73	2.94	0.04	-1.27
Delay Time		30	0.13	0.43	0.28	0.08	0.02	-0.86
Average Velocity		30	2.65	3.54	2.94	0.21	1.01	1.11
Average Acceleration		30	1.37	2.10	1.71	0.20	-0.03	-0.99
Time to Skate 6m		30	1.69	2.26	2.05	0.14	-0.66	0.17
DST	1	30	-0.08	0.08	0.02	0.04	-0.42	0.82
	2	30	0.00	0.08	0.03	0.02	0.62	-0.35
	3	30	-0.02	0.10	0.03	0.03	0.52	-0.29
	4	30	0.00	0.10	0.04	0.03	0.39	-0.20
PT	1	0	0.00	0.00	0.00	0.00	0.00	0.00
	2	30	0.20	0.40	0.30	0.05	-0.07	-0.79
	3	30	0.23	0.43	0.32	0.05	0.26	-0.48
	4	30	0.22	0.47	0.34	0.06	0.19	-0.08
Stride Rate		30	2.46	3.57	2.90	0.29	0.37	-0.38
HA-p#	1	30	115.84	172.56	151.83	13.01	-1.06	1.26
	2	30	138.53	174.04	155.16	9.68	-0.03	-0.95
	3	30	131.51	166.22	148.41	9.36	0.13	-0.70
	4	30	109.42	172.28	145.69	15.73	-0.43	-0.21
	5	30	127.68	162.90	144.97	10.28	0.21	-0.99
HA-t#	1	30	77.02	130.64	97.51	12.01	0.77	0.78
	2	30	70.30	166.22	92.97	17.73	2.57	9.71
	3	30	60.54	119.54	87.50	11.11	0.51	1.81
	4	30	64.90	156.35	89.10	16.23	2.48	9.83
	5	30	64.31	102.85	85.21	9.51	-0.16	-0.55
FLA-p#	1	30	32.25	64.47	49.14	8.08	-0.01	-0.51
	2	30	19.79	66.03	41.32	9.47	0.34	1.22
	3	30	25.70	59.14	38.88	7.74	0.63	0.13
	4	30	17.60	57.37	36.34	9.72	-0.14	-0.17
	5	30	19.41	55.91	35.65	9.29	0.15	-0.53
FLA-t#	1	30	41.01	70.28	52.51	8.17	0.60	-0.45
	2	30	22.45	66.43	49.11	9.32	-0.54	1.00
	3	30	32.29	66.29	46.94	7.99	0.65	-0.02
	4	30	25.09	66.11	46.91	8.46	-0.12	0.92
	5	30	29.85	59.78	45.09	8.13	-0.03	-0.86
KA-p#	1	30	116.22	170.24	153.13	11.50	-1.16	2.64
	2	30	138.40	171.94	156.18	8.44	-0.34	-0.46
	3	30	144.28	170.70	155.56	6.47	0.54	-0.11
	4	30	136.71	169.76	156.39	7.87	-0.60	0.11
	5	30	140.83	170.85	157.40	6.38	-0.41	0.52

KA-t#	1	30	90.37	121.78	107.14	7.87	0.14	-0.24
	2	30	89.76	150.95	103.52	11.69	2.40	8.70
	3	30	79.72	117.95	100.60	7.38	0.05	1.95
	4	30	87.37	155.10	103.34	12.22	2.65	10.69
	5	30	82.68	117.91	101.98	9.07	-0.31	-0.32
AA-p#	1	30	72.46	105.97	93.77	8.00	-0.81	0.56
	2	30	85.23	129.58	100.15	8.49	1.29	4.13
	3	30	88.98	118.66	100.36	5.33	0.81	4.24
	4	30	74.39	132.24	100.36	10.59	-0.08	3.23
	5	30	84.90	116.30	102.15	6.09	-0.64	1.68
PA-p#	1	30	67.29	109.26	85.54	11.10	0.31	-0.56
	2	30	46.68	98.56	75.00	11.53	-0.36	0.64
	3	30	31.10	91.03	67.59	14.54	-0.59	-0.16
	4	30	32.35	119.72	63.75	19.89	0.35	0.65
	5	30	25.48	87.66	59.91	13.88	-0.40	0.15
TOA-p#	1	30	47.13	84.11	55.11	7.14	2.72	9.53
	2	30	47.15	61.45	53.76	3.35	0.32	0.16
	3	30	45.05	60.50	52.85	3.70	0.07	-0.25
	4	30	40.70	60.37	51.90	3.64	-0.53	2.44
	5	30	41.04	63.35	51.54	5.08	-0.17	0.13
HAB-p#	1	30	9.96	36.17	25.55	7.08	-0.87	-0.01
	2	30	15.92	37.83	27.72	6.14	0.00	-0.75
	3	30	14.20	33.13	24.64	5.42	-0.05	-1.07
	4	30	7.52	38.60	22.39	7.94	-0.07	-0.60
	5	30	9.59	35.42	23.92	6.38	-0.40	-0.17
SV-t#	1	30	-49.18	134.71	85.10	47.82	-1.72	2.18
	2	30	41.29	121.65	86.91	20.85	-0.30	-0.38
	3	30	30.21	116.40	65.13	22.87	0.58	-0.44
	4	30	19.34	107.31	57.83	22.43	0.44	-0.19
	5	30	14.54	96.71	49.73	22.30	0.99	-0.11
HCM-t#	1	30	0.67	0.85	0.76	0.04	-0.15	-0.51
	2	30	0.66	0.84	0.75	0.04	-0.14	-0.26
	3	30	0.63	0.85	0.75	0.05	-0.25	0.73
	4	30	0.63	0.83	0.74	0.04	-0.25	0.49
	5	30	0.62	0.84	0.73	0.04	0.18	1.13
SF/E-p#	1	30	0.63	55.16	20.88	16.05	0.80	-0.25
	2	30	0.28	67.24	24.13	17.32	0.58	-0.35
	3	30	1.41	50.30	20.38	14.75	0.77	-0.46
	4	30	1.26	46.12	19.90	14.07	0.44	-1.11
	5	30	0.27	67.85	22.70	16.74	0.82	0.44
SF/E-t#	1	30	0.35	66.44	30.00	18.78	-0.03	-0.99
	2	30	4.26	72.62	48.66	19.56	-0.66	-0.47
	3	30	7.78	65.77	39.11	17.02	0.02	-0.92
	4	30	2.87	76.39	43.29	20.91	-0.33	-0.78
	5	30	13.07	69.13	40.86	15.26	0.09	-0.71

SA/A-p#	1	30	0.24	82.82	35.07	21.81	0.59	-0.42
	2	30	0.28	56.86	23.59	14.31	0.44	-0.59
	3	30	1.72	58.71	21.35	13.51	0.55	0.61
	4	30	0.39	52.73	14.90	11.52	1.14	2.40
	5	30	1.36	43.45	19.10	10.66	0.64	0.08
SA/A-t#	1	30	2.85	82.52	48.66	19.31	-0.23	-0.03
	2	30	1.08	78.89	29.62	19.89	0.99	0.62
	3	30	2.72	76.62	44.77	19.54	-0.29	-0.85
	4	30	3.03	81.07	35.54	20.31	0.48	-0.50
	5	30	13.81	76.93	44.02	17.36	-0.18	-0.89
SL#	1	30	0.56	1.69	1.24	0.27	-1.14	1.65
	2	30	1.12	1.98	1.50	0.17	0.55	1.36
	3	30	1.33	1.98	1.65	0.15	0.20	0.10
	4	30	1.49	2.26	1.77	0.20	0.92	0.10
	5	30	1.57	2.45	1.91	0.17	0.84	2.26
MHRF#	1	30	0.04	0.15	0.10	0.03	-0.29	-0.42
	2	30	0.07	0.29	0.13	0.05	1.54	3.13
	3	30	0.04	0.19	0.11	0.04	0.05	-0.70
	4	30	0.01	0.19	0.12	0.04	-0.85	1.89
	5	30	0.03	0.25	0.12	0.04	0.65	1.83
HA.t-p	1	30	-70.38	-22.62	-50.90	11.12	0.87	0.85
	2	30	-79.98	-2.43	-52.72	15.91	1.25	2.59
	3	30	-84.80	-30.93	-57.47	13.28	-0.15	-0.61
KA.t-p	1	30	-69.35	-25.87	-48.43	10.73	0.14	-0.39
	2	30	-69.99	-13.24	-52.87	12.50	1.04	1.97
	3	30	-79.17	-32.67	-56.80	9.37	0.25	0.91
LA.t-p	1	30	2.37	40.41	13.64	8.42	1.16	2.17
	2	30	-2.28	28.19	12.77	7.91	0.15	-0.65
	3	30	-6.11	34.06	11.28	9.74	0.21	-0.14
Average Horizontal Velocity Over 5 Strides		30	3.00	4.11	3.52	0.27	0.21	-0.03

Appendix G: Independent Samples t-Tests Between Level

Group Statistics

Variable	Level of Play	N	Mean	Std. Deviation	Std. Error Mean
Time to Skate 6m	A	13	2.07	0.10	0.03
	AA	17	2.03	0.16	0.04
Player Height	A	13	144.60	7.23	2.00
	AA	17	145.53	5.87	1.42
Player Weight	A	13	35.96	7.02	1.95
	AA	17	36.19	6.28	1.52
Delay Time	A	13	0.30	0.08	0.02
	AA	17	0.28	0.08	0.02
Average Horizontal Velocity Over 5 Strides	A	13	3.48	0.23	0.06
	AA	17	3.54	0.31	0.07

t-Tests for Equality of Means

Variable	t	df	Significance	95% Confidence Interval of the Difference	
				Lower	Upper
Time to Skate 6m	0.658	28	0.516	-0.071	0.138
Player Height	-0.390	28	0.700	-5.828	3.965
Player Weight	-0.093	28	0.927	-5.212	4.759
Delay Time	0.715	28	0.480	-0.039	0.080
Average Horizontal Velocity Over 5 Strides	-0.566	28	0.576	-0.266	0.151

Appendix H: Independent Samples t-Tests Between Position

Group Statistics

Variable	Position Played	N	Mean	Std. Deviation	Std. Error Mean
Time to Skate 6m	F	20	2.05	0.12	0.03
	D	8	2.02	0.18	0.06
Player Height	F	20	144.53	6.80	1.52
	D	8	146.69	6.18	2.19
Player Weight	F	20	35.30	6.22	1.39
	D	8	38.92	7.29	2.58
Average Horizontal Velocity Over 5 Strides	F	20	3.52	0.22	0.05
	D	8	3.55	0.41	0.15

t-Tests for Equality of Means

				95% Confidence Interval of the Difference	
Variable	t	df	Significance	Lower	Upper
Time to Skate 6m	0.453	26	0.654	-0.095	0.149
Player Height	-0.775	26	0.445	-7.859	3.555
Player Weight	-1.328	26	0.196	-9.239	1.986
Average Horizontal Velocity Over 5 Strides*	-0.211	8.606	0.838	-0.382	0.317

* Equal Variances Not Assumed as per LeVene's Test

Appendix I: Correlations with Time to Skate Six Metres

Variable		N	r	Significance
DST	1	30	-0.086	0.653
	2	30	-0.041	0.829
	3	30	0.059	0.758
	4	30	0.040	0.832
PT	1	0	0	0
	2	30	-0.204	0.280
	3	30	0.046	0.809
	4	30	-0.013	0.945
Stride Rate		30	0.095	0.619
HA-p#	1	30	-0.279	0.135
	2	30	-0.128	0.500
	3	30	0.066	0.729
	4	30	0.107	0.575
	5	30	-0.075	0.695
HA-t#	1	30	0.292	0.118
	2	30	0.253	0.178
	3	30	0.324	0.081
	4	30	0.336	0.069
	5	30	0.399	0.029
FLA-p#	1	30	0.196	0.299
	2	30	0.173	0.362
	3	30	0.241	0.199
	4	30	0.459	0.011
	5	30	0.228	0.227
FLA-t#	1	30	0.053	0.782
	2	30	0.013	0.945
	3	30	0.196	0.300
	4	30	0.139	0.464
	5	30	0.137	0.469
KA-p#	1	30	-0.308	0.097
	2	30	-0.375	0.041
	3	30	-0.347	0.060
	4	30	-0.261	0.163
	5	30	-0.215	0.254
KA-t#	1	30	0.342	0.065
	2	30	0.405	0.026
	3	30	0.331	0.074
	4	30	0.364	0.048
	5	30	0.367	0.046
AA-p#	1	30	-0.264	0.158
	2	30	-0.004	0.984
	3	30	-0.044	0.819
	4	30	0.095	0.617
	5	30	-0.060	0.754

PA-p#	1	30	-0.023	0.902
	2	30	0.125	0.510
	3	30	-0.033	0.863
	4	30	0.046	0.810
	5	30	0.176	0.353
TOA-p#	1	30	0.468	0.009
	2	30	0.585	0.001
	3	30	0.538	0.002
	4	30	0.491	0.006
	5	30	0.432	0.017
HAB-p#	1	30	-0.256	0.173
	2	30	-0.445	0.014
	3	30	-0.250	0.183
	4	30	-0.289	0.121
	5	30	-0.350	0.058
SV-t#	1	30	-0.029	0.880
	2	30	0.186	0.324
	3	30	0.114	0.549
	4	30	0.021	0.914
	5	30	0.304	0.103
HCM-t#	1	30	0.276	0.140
	2	30	0.127	0.504
	3	30	0.187	0.323
	4	30	0.294	0.115
	5	30	0.382	0.037
SF/E-p#	1	30	-0.075	0.692
	2	30	0.083	0.664
	3	30	0.043	0.820
	4	30	-0.101	0.596
	5	30	-0.177	0.350
SF/E-t#	1	30	0.061	0.747
	2	30	-0.266	0.156
	3	30	0.175	0.354
	4	30	-0.105	0.580
	5	30	0.202	0.284
SA/A-p#	1	30	0.075	0.693
	2	30	0.270	0.149
	3	30	0.177	0.351
	4	30	0.166	0.380
	5	30	0.350	0.058
SA/A-t#	1	30	-0.169	0.371
	2	30	-0.013	0.944
	3	30	-0.245	0.191
	4	30	0.029	0.879
	5	30	-0.211	0.264

SL#	1	30	-0.582	0.001
	2	30	-0.640	0.000
	3	30	-0.513	0.004
	4	30	-0.623	0.000
	5	30	-0.543	0.002
MHRF#	1	30	-0.356	0.053
	2	30	-0.267	0.154
	3	30	0.183	0.334
	4	30	-0.381	0.038
	5	30	-0.204	0.280
HA.t-p#	1	30	0.259	0.166
	2	30	0.176	0.351
	3	30	0.239	0.076
KA.t-p#	1	30	0.460	0.011
	2	30	0.543	0.002
	3	30	0.407	0.026
LA.t-p#	1	30	-0.171	0.367
	2	30	-0.548	0.002
	3	30	-0.056	0.767

Appendix J: Correlations with Average Horizontal Velocity Over Five Strides

Variable		N	r	Significance
DST	1	30	0.155	0.414
	2	30	0.189	0.317
	3	30	-0.009	0.963
	4	30	0.125	0.512
PT	1	0	0	0
	2	30	0.365	0.047
	3	30	0.044	0.819
	4	30	0.129	0.498
Stride Rate		30	-0.360	0.050
HA-p#	1	30	0.453	0.012
	2	30	0.324	0.080
	3	30	-0.160	0.399
	4	30	-0.199	0.293
	5	30	0.168	0.374
HA-t#	1	30	-0.246	0.189
	2	30	-0.244	0.194
	3	30	-0.291	0.119
	4	30	-0.356	0.054
	5	30	-0.393	0.032
FLA-p#	1	30	-0.276	0.140
	2	30	-0.139	0.463
	3	30	-0.216	0.252
	4	30	-0.413	0.023
	5	30	-0.075	0.694
FLA-t#	1	30	-0.069	0.718
	2	30	-0.002	0.992
	3	30	-0.164	0.386
	4	30	-0.164	0.386
	5	30	-0.191	0.311
KA-p#	1	30	0.393	0.032
	2	30	0.533	0.002
	3	30	0.276	0.140
	4	30	0.222	0.238
	5	30	0.289	0.121
KA-t#	1	30	-0.402	0.028
	2	30	-0.374	0.042
	3	30	-0.258	0.168
	4	30	-0.401	0.028
	5	30	-0.412	0.024
AA-p#	1	30	0.219	0.245
	2	30	0.026	0.891
	3	30	-0.003	0.988
	4	30	-0.185	0.328
	5	30	0.035	0.855

	1	30	-0.082	0.668
PA-p#	2	30	-0.196	0.298
	3	30	-0.050	0.792
	4	30	-0.057	0.763
	5	30	-0.137	0.472
TOA-p#	1	30	-0.613	0.000
	2	30	-0.657	0.000
	3	30	-0.564	0.001
	4	30	-0.508	0.004
	5	30	-0.445	0.014
HAB-p#	1	30	0.418	0.022
	2	30	0.523	0.003
	3	30	0.244	0.195
	4	30	0.129	0.498
	5	30	0.409	0.025
SV-t#	1	30	0.175	0.355
	2	30	-0.356	0.053
	3	30	-0.266	0.155
	4	30	-0.124	0.514
	5	30	-0.438	0.016
HCM-t#	1	30	-0.312	0.094
	2	30	-0.222	0.239
	3	30	-0.248	0.186
	4	30	-0.336	0.070
	5	30	-0.374	0.042
SF/E-p#	1	30	0.056	0.768
	2	30	-0.132	0.488
	3	30	-0.073	0.700
	4	30	-0.020	0.915
	5	30	0.175	0.355
SF/E-t#	1	30	0.052	0.786
	2	30	0.169	0.372
	3	30	-0.148	0.436
	4	30	0.173	0.359
	5	30	-0.157	0.408
SA/A-p#	1	30	-0.189	0.318
	2	30	-0.203	0.281
	3	30	-0.271	0.147
	4	30	-0.143	0.452
	5	30	-0.476	0.008
SA/A-t#	1	30	0.077	0.687
	2	30	0.055	0.772
	3	30	0.247	0.189
	4	30	-0.127	0.502
	5	30	0.189	0.316

SL#	1	30	0.744	0.000
	2	30	0.731	0.000
	3	30	0.547	0.002
	4	30	0.586	0.001
	5	30	0.391	0.032
MHRF#	1	30	0.631	0.000
	2	30	0.237	0.207
	3	30	-0.194	0.305
	4	30	0.140	0.461
	5	30	0.055	0.774
HA.t-p#	1	30	0.019	0.922
	2	30	-0.293	0.116
	3	30	-0.114	0.549
KA.t-p#	1	30	0.318	0.087
	2	30	-0.370	0.044
	3	30	-0.014	0.941
LA.t-p#	1	30	-0.175	0.354
	2	30	0.119	0.530
	3	30	-0.304	0.103

Appendix K: Multiple Backwards Stepwise Regression

Table K1
Regression with time to skate six metres (32 variables entered)

Model 2	Unstandardized Coefficients		Standardized Coefficients		
	Beta	Std. Error	Beta	t	p
(Constant)	-0.23	0.01		-21.17	0.03
PT-2	1.10	0.01	0.41	179.35	0.00
HA-p1	0.01	0.00	0.64	332.36	0.00
HA-t5	-0.01	0.00	-0.86	-256.53	0.00
FLA-p4	0.00	0.00	0.08	35.99	0.02
KA-p1	0.00	0.00	0.33	165.77	0.00
KA-p2	-0.01	0.00	-0.86	-347.26	0.00
KA-t1	0.00	0.00	-0.21	-56.97	0.01
KA-t4	0.00	0.00	-0.12	-51.53	0.01
KA-t5	0.00	0.00	-0.14	-58.07	0.01
TOA-p1	-0.01	0.00	-0.26	-97.87	0.01
TOA-p2	0.03	0.00	0.80	302.19	0.00
TOA-p3	0.01	0.00	0.17	79.18	0.01
HAB-p1	-0.01	0.00	-0.67	-216.58	0.00
HAB-p2	0.03	0.00	1.36	307.04	0.00
HAB-p5	0.02	0.00	1.07	318.72	0.00
SV-t5	0.00	0.00	-0.05	-22.87	0.03
HCM-t5	5.57	0.02	1.78	290.24	0.00
SA/A-p2	0.01	0.00	0.69	482.21	0.00
SL-1	-0.66	0.00	-1.28	-341.84	0.00
SL-3	0.08	0.00	0.08	31.18	0.02
SL-5	-1.06	0.00	-1.34	-447.89	0.00
MHRF-4	0.26	0.01	0.07	46.76	0.01
HA.T_P.3	0.01	0.00	0.54	319.82	0.00
KA.T_P.1	-0.01	0.00	-0.84	-211.03	0.00
KA.T_P.3	0.00	0.00	0.09	47.53	0.01
LA.T_P.2	0.00	0.00	-0.26	-79.24	0.01
Player Height	0.00	0.00	0.18	67.02	0.01
Player Weight	-0.02	0.00	-1.02	-215.16	0.00

Table K2

Regression with time to skate six metres (18 variables entered)

Model 2	Unstandardized Coefficients		Standardized Coefficients		
	Beta	Std. Error	Beta	t	p
(Constant)	1.283	0.277		4.634	0.000
KA-SL1	0.0004	0.000	0.135	0.956	0.349
KA-t1	0.0007	0.002	0.402	3.031	0.006
PWR-3	-0.246	0.166	-0.206	1.488	0.150
HAB-p5	-0.005	0.003	-0.220	1.533	0.139
LA.T_P.2	-0.008	0.003	-0.485	3.211	0.004
Player Weight	0.006	0.003	0.295	2.150	0.042