Dynamic strain profile of the ice hockey stick:

Comparisons of calibre and stick shaft stiffness

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Abstract

The primary purpose of this study was to develop a method to quantify the dynamic strain profile (DSP) of an ice hockey stick's shaft, and secondly, to use this method to assess the potential influence of player skill calibre and stick shaft properties on DSP during both the slap and wrist shots. Seventeen adult males performed a series of shots using two different stiffness ranked sticks in a laboratory setting on synthetic ice surface. These subjects were subdivided as high and low calibre players. Dependent measures included were: 1) five paired strain gauge responses along the shaft's length recorded at 10 KHz, and 2) kinematics of the puck, stick and trail arm grasping the stick recorded at 300 Hz using a Vicon MX ™ system. 2 x 2 MANOVAs were conducted for each of slap shot and wrist shot trials. The results demonstrated the feasibility of quantifying DSP such that an unambiguous rank order in maximum strain responses was obtained. Further, DSP were sensitive to both factors of player calibre and stick stiffness properties; that is, greater bend induced strains observed by high calibre player and lower stiffness sticks. Two kinematic differences relating to technique were observed: high calibre players showed less elbow flexion during the slap shot and greater wrist flexion during wrist shots. Lastly, with regards to time to maximum strain, high calibre players performed slap shots 3 to 4 times faster than the lower calibre players.

Résumé

L'objectif principal de cette étude était de développer une méthode pour la quantification des différents profils de déformation dynamique de bâtons de hockey et de utiliser qu'est méthode pour examiner l'influence cinématiques du des joueurs de niveau élite et des joueurs de niveau récréatif pour les lancers frappes (SS) et des tirs du poignet (WS). Dix-sept sujets males ont donc effectué en laboratoire une série SS et de WS avec deux bâtons de hockey différent sur une surface de glace synthétique et étaient divisés en deux groupes, un pour le niveau élite et l'autre pour le niveau récréatif. Les mensures dépendantes étaient 1) la déformation du bâton a cinq étroits sur le manche du bâton à l'aide d'un système maison enregistrant à une fréquence de 10 KHz, et 2)la cinématique du bâton, de la rondelle et du membre supérieur le plus bas sur le bâton ont été enregistré à une fréquence de 300 Hz à l'aide d'un système Vicon MX ™. Deux MANOVA de forme 2x2 ont été effectuées, une pour les lancers frappés ainsi qu'une pour les lancers du poignet. Les résultats ont démontré la faisabilité de la quantification des différents profils de déformation dynamique de bâtons telle que l'ordre de classement sans ambigüité en réponse contrainte maximale a été obtenue. Des différences ont été trouvées pour la déformation aux différents capteurs à travers les niveaux d'habileté ainsi qu'à travers les bâtons. La déformation maximale était différente dépendamment du calibre et du

bâton et ce pour les deux types de lancer. De plus, les joueurs de calibre récréatifs ont démontrés un délai significativement plus long entre la déformation maximal et le début du lancer pour les lancers frappés. Des différences cinématiques ont été trouvées au moins flexion du coude entre les calibres pour le niveau élite pour les lancers frappés et plus flexion pour le poignet pour les tirs du poignet pour le niveau élite. Pour terminer, la vitesse de chargement et de déchargement étaient différentes pour les différents calibres et pour les différents bâtons.

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Chapter 1: Introduction

1.0 Introduction

Hockey is an essential part of Canadian culture, with over 500,000 participants registered in a nationally recognized hockey program. This group of participants does not include those individuals who play recreationally, in adult leagues or in summer leagues (Hockey Canada, 2007). Hockey has developed from a grassroots recreational activity of the first nations to the technical sport that it is today via grand changes in equipment, facilities, rules and the way modern athletes train.

One of the most visible pieces of equipment in the game of ice hockey is the stick, a diagram can be seen in Appendix I. The hockey stick is used by the hockey player as an extension of the arm, mainly to manipulate the puck in a pass or by taking a shot. Additional uses include taking face offs and for defensive purposes such as when blocking a pass, and stick handling and checking.

The use of the stick to manipulate the puck can be seen in shooting tasks, especially when looking at slap and wrist shots, which are the two most common shots employed by hockey players (Montgomery et al, 2004). The slap shot (SS), a broad shot with a large back swing, in particular, is spectacular in nature due to the fact that the puck can reach high velocities, somewhere in the range of 100 to

115 km/h for the standing SS (Pearsall et al., 2000). Nazar (1971) looked at both the skating and the standing slap shot and reported the skating SS is the fastest shot, albeit, most inaccurate. The standing wrist shot (WS), a shot with minimal back swing and much slower than the SS, is the most accurate shooting technique, while skating and taking a WS diminishes the level of precision (Nazar, 1971).

Since a high puck velocity is an important objective of a hockey shot, it is imperative to understand how the stick and puck relate to one another. Many factors are known to affect the velocity of the puck significantly, including, but not limited to the velocity of the lower end of the stick prior to contact, the pre-loading phase, the ability to transfer elastic energy from loading the stick to the kinetic energy of the puck via the elastic stiffness of the shaft, the contact time with the puck, as well as the body size and strength of the individual shooting (Doré and Roy, 1973, Hoerner, 1989, Marino, 1998, Worobets, 2003, Wu, 2003, Michaud-Paquette, 2008).

Wu and colleagues (2003) observed that puck speed increases with skill level and that hockey players of a higher calibre manipulate the stick differently. Several other studies looked at the skill level of the players and how performance differed. Woo and colleagues (2004) inspected how the stick was used to create such a divide between recreational and elite shooters, illustrating the importance of technique in addition to characteristics of the stick itself as a key component of puck velocity. Villaseñor et al. (2005) compared differences in the loading of the stick between these two groups as well. In addition to these comparisons between calibre of player, Lomond (2007) reported differences in velocity in the slap shot and differences in kinematics of the shooter based on skill level.

Both the mechanical contributions, such as stiffness of the hockey stick shaft and the kinematics of the shooter must be analyzed collectively, to gain a deeper understanding of the relationship between the properties of the tool used and how the athete uses the hockey stick to optimize shooting technique.

1.1 Nature and Scope of the Problem

Over the years, technology has improved drastically, allowing researchers to achieve greater accuracy when studying the kinematics of an individual during a task and the ability to analyze mechanical properties of tools used by humans on a day to day basis. With respect to motion capture, it is quite difficult to evaluate data in an on ice situation due to the difficulty in obtaining optimal lighting conditions, the cost of ice rental, the effect of cold temperature on operation of the equipment and the large field of view needed to carry out the data collection on shots taken while skating (Lafontaine et al, 2007). By collecting motion data in a controlled laboratory environment, it allows for a more reliable description of the kinematics performed by the shooter as well as consistent data describing the hockey stick's mechanical attributes. Comparing the differences in kinematics and the way the stick is manipulated between high and low calibre shooters in both slap and wrist shots allows for players to better understand how to optimize the way they use the hockey stick by altering technique, creating a more effective shot. Investigating the role of shaft stiffness and puck velocity under the different shooting conditions and level of player may allow for more understanding of how the stick itself can affect shooting velocity.

In the present study, the shooting protocol was performed on a synthetic ice surface in a laboratory environment, allowing for better control of the placement of motion capture cameras, better lighting conditions, as well as making the study more cost-effective. The synthetic ice has similar physical attributes to regular ice, but it has a higher coefficient of friction which is reported to be $\mu \approx 0.28$ by Viking® ice. Real ice varies in friction coefficient depending on temperature, humidity and area of the ice surface but is generally, slightly lower. The ability to perform the protocol in the laboratory allows for a more time effective data collection where all anthropometric data and both shooting and bending stick tests could be performed at any time the subjects were available, and thus, the synthetic ice is a more practical alternative for this type of data collection than real ice.

1.2 Rationale

As has been discussed, some interesting findings have been uncovered with respect to elite versus recreational shooters and how these two distinct groups physically react to using hockey sticks with distinct mechanical properties. By investigating the role of stiffness of the shaft, through analysis of the dynamic strain profile it is possible to acquire valuable information needed to better understand the differences in stick manipulation at different skill levels. This information could help understand how to optimize force application to the puck to increase shot velocity.

More detailed examination of the kinematics of the shooter in concert with the stick strain properties along the shaft of the stick observed during the SS and WS across a wide range of shooters could yield information which could help give insight into effective ways to use a hockey stick and the technique to achieve a shot with more velocity. Visualizing the maximum strain in the x (forward-backward) direction, at the gauge placement sites and timing of the peak strain down the shaft will illustrate how the majority of strain is translated down the stick from the hands down to the puck while the stick is being loaded in that direction. The research in this area is minimal and observing shooter kinematics and how the stick is manipulated by different calibres of player, as well as how the player optimizes the flexibility characteristics of shaft may prove insightful in broadening the knowledge base of this topic for athletes, coaches, and the sporting goods industry.

1.3 Objectives and Hypotheses of Proposed Research

The overall goal of this study was to describe the differences in dynamic strain profile (DSP) in the x direction and in upper body kinematics between high and low calibre (HC, LC) shooters and between two hockey sticks with varying stiffness properties for the SS and WS. It is clear that there are both mechanical and human factors that contribute to the success of a shot in ice hockey. Examining the kinematics of the stick and body and how the DSP is affected as it moves through the shaft to the blade will help to understand how good shooters optimize the use of the stick with a given set of characteristics. Hypotheses related to this study are outlined below.

Greater maximum in peak strain, time to peak strain, and strain load and decay rates will be seen in:

- HC versus LC shooters
- Less stiff shaft versus more stiff shaft
- Greatest strain per trial will correspond to the bottom hand placement
- Ordered response in time to peak strain where the strain gauge closest to the top hand reaches a maximum more rapidly while the gauge closest to the blade will have the latest peak strain.

- Differences expected based on HC vs. LC of play will yield:
    - Higher grip strength values
    - Increased duration of contact time
    - Longer time to peak strain
    - Increased flexion of stick
    - Wider hand placement
    - Wider base of support
- Increased variability of wrist and elbow angle kinematics

1.4 Operational Definitions

In addition to a table of abbreviations in Appendix II, some important definitions are highlighted below.

Contact time	The time elapsed between the point of contact of the blade of the stick with the puck, until the puck's release from the blade.
Dynamic Strain Profile (DSP)	The change in magnitudes of the 5 strain gauges during flexion along the x direction of the shaft of the hockey stick during contact time normalized to shooter strength, as seen below in figure 1.

Player calibre	Calibre of player was stratified based on current level of play during testing.
Flex profile	The number assigned to a hockey stick to describe the stiffness of the shaft; lower numbers are indicative of a less rigid shaft.

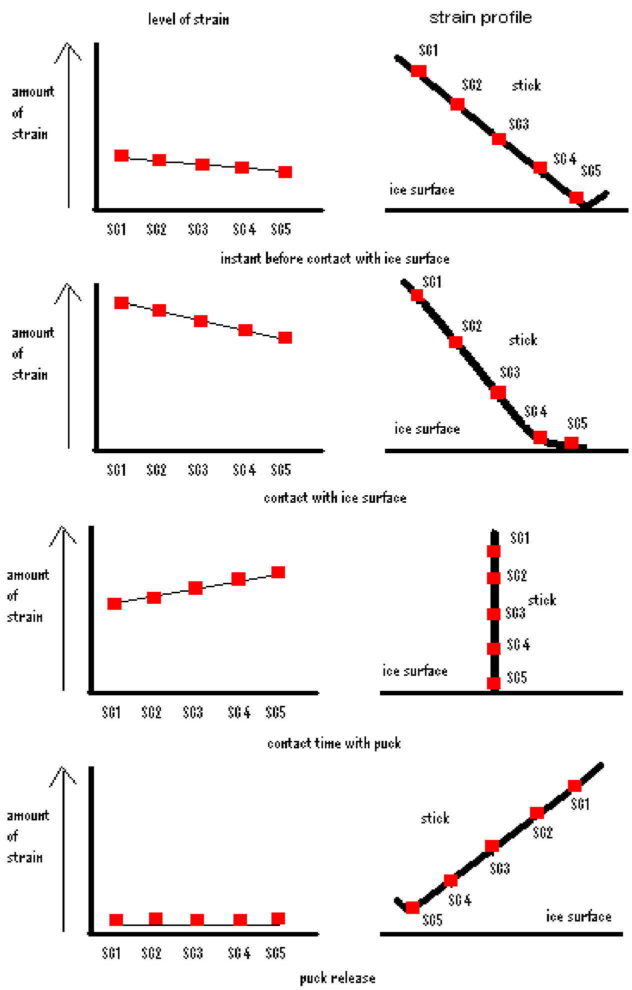

Figure 1: Dynamic strain profile (strain variation along the shaft's length) as a temporal function of impact. Strain values shown are only speculative.

1.5 Contribution to the Field

Kinematic data of the upper body throughout the SS and WS may provide a basic framework for the understanding of how HC players' technique differs from that of LC and how that affects the force application to the stick and how it affects the DSP. With both kinematics and stick response to the kinematics of the shooter taken into account a deepening of our understanding of effective manipulation of the stick for shooting, and perhaps how the stick characteristics can be optimized for effective player use may be possible.

1.6 Limitations and Delimitation of this Study

Although this study strives to be both internally and externally valid, there are some limitations and delimitations associated with the research design, including:

1.6.1 Limitations

- The experiments were conducted under laboratory conditions with an artificial surface covered by lubricated polyethylene used to simulate ice conditions.
- The laboratory experiments were conducted at room temperature (22 to 24 °C). Finally, these experiments were not performed in a real game situation.

1.6.2 Delimitations:

- The protocol only examined standing slap and wrist shots from 3.5 m at a 90° angle from the center of an open net.
- Only male shooters in the 18 to 35 year old age range were observed.
- Only one blade pattern and one stick model with two different shaft stiffness ratings were used during the study.
- Strain gauges were placed at five locations along the shaft, every 200mm, measuring strain in only the x direction.
- Level of play was used to determine the calibre of players, where HC was defined as university level play or above and LC was recreational play.
- The subjects used their own skates.

Chapter 2: Review of Literature

2.0 Review of literature

Research on shooting in ice hockey has predominantly focused on the SS and WS kinematics. There is a limited amount of research evaluating the mechanical properties of the hockey stick, such as stiffness. Although there is some research examining both kinematics and mechanical properties of SS and WS individually, combining these parameters may allow for additional understanding of how a shooter employs the hockey stick to get a resultant shot, as well as how the stiffness of the shaft affects that manipulation. Enough research has been done on golf, field hockey and ice hockey collectively to create insightful research questions pertaining to how one manipulates the ice hockey stick to increase the success of their shot. Thus, a review of literature regarding research of similar nature has been conducted, focusing on the evolution of the hockey stick, kinematics of the slap and wrist shots, engineering beam theory and the effect of stiffness on the resultant shot.

2.1 Evolution of the hockey stick

One of Canada's most famous pastimes, ice hockey, was derived from Eastern Canada's strong English, Scottish, Irish and French heritages in the 1800s. It is postulated that the Irish game of hurley had one of the strongest influences on the development of this great Canadian sport (Vaughan, 1996). As the game evolved over some 200 years, so did the equipment, namely the hockey stick. The stick used in ice hockey may be a derivative of the stick used in hurley, an Irish game. In the late 1880s, the Mi'kmaq created once piece wooden sticks, approximately 44 inches (111.76 cm) in length crafted out of naturally curved hornbeam, also known as ironwood. As this wood became less available, yellow birch was looked to as the main source for hockey stick manufacturing (Vaughan, 1996). The use of tape started in the early 1900s to increase the longevity of the stick and to increase accuracy and ease of shooting the puck (Major, 1936). As Western Society entered the machine age, the 1930s led the way for the lamination of sticks as well as the introduction of 2 and 3-piece sticks. These sticks were predominantly made of Canadian Rock Elm, some also had a Hickory heel piece, and were no more than 54 inches (137.16 cm) tall (Major, 1936).

Over the 1900s, several developments set the path towards what is now recognized as today's standard hockey stick. In the 1950s, the use of separate blade and shaft components were introduced, followed in the 1960s by adding a curved blade, increasing the shooting velocity, as well as the manoeuvrability of the puck (Nazar, 1971, Pearsall, Turcotte & Murphy, 2000). In the 1970s, the wooden sticks were enveloped with fiberglass and plastic coats, decreasing the overall weight of the stick. Increases in durability of the stick blade were seen in the 1980s with the insertion of plastic to the blade, and finally, the 1990s dabbled in the use of alternate materials such as aluminum alloys, carbon plastics and fibreglass one-piece sticks, common to what we see today (Pearsall et al., 2000). These more modern sticks are to be a minimum of 25 inches (63cm) in length and a maximum blade curvature in deflection of 0.2 cm (0.5 inches) (Duplacey, 1996). As technology has changed over the years with regard to the composition and style of the stick, thorough research is warranted regarding the mechanical attributes of the stick and puck.

A modern hockey stick can be a costly piece of sporting equipment and is prone to breaking. Roy and Delisle (1984) believe that the durability of a stick is based on four factors which include the width of the handle, the thickness of the handle, the rupture coefficient, and lastly, the rigidity of the handle and of the hosel. Static and dynamic characteristics to take into account with respect to the engineering of high quality hockey sticks include blade stiffness, minor and major axis shaft stiffness, in addition to torsional stiffness of the shaft. These factors influence the amount of elastic energy that can be stored in the stick during a shot (Pearsall et al, 2000). There are also several geometric characteristics that must be considered with respect to the engineering of hockey sticks including length, minor and major axis dimensions, length and thickness of shaft, curvature of blade, lie (angle between shaft and blade), and centre of mass for players perception of the 'feel' of the stick and game regulations (Pearsall et al., 2000).

2.2 Kinematics

Kinematics is a branch of biomechanics concerned with the characteristics and examination of motion from the perspectives of space and time without reference to the forces causing motion (Hamill & Knutzen, 2003). Although the field of human movement kinematic analysis with advanced technology is relatively recent, observations in reference to human movement analysis have been noted as far back as 2000 years ago. For example, Aristotle made the first reference to the idea of walking analysis by commenting on the vertical displacement of an individual as they walk (Baker, 2007). Although he hypothesized about walking characteristics, it was not until Borelli that the first gait experiment was conducted over a thousand years later (Baker, 2007). Borelli also conducted experiments of motion analysis in running, jumping and skating tasks as well and is considered the pioneer of the modern field of biomechanics (Clarys & Alewaeters, 2003). In the late 1800s, Braun and Fisher noted that individual joint angles and the displacement of segments of whole body mass should be recognized as essential measurement requirements in the analysis of movement (Sutherland, 2002). Braun and Fisher used cameras in total darkness with focused areas of light attached to a bodysuit worn by the subject (Sutherland, 2002).

By the 1940s, interrupted light became a standard approach to gait analysis, pioneered by Inman and Eberhardt (Sutherland, 2002). White light markers were used at joint centres and after the film was developed the researchers would connect the dots of the markers in order to conduct their analyses (Sutherland, 2002). A key issue with this approach is the accuracy of the marker system. Since the markers are attached to the skin instead of anchored directly to the bone, movement of the markers occurred. Inman attempted to resolve this problem by drilling pins directly into the bone in order to minimize marker movement. Although this approach was more accurate, it caused severe pain in the subjects and due to its invasive nature, it is not a popular approach to movement analysis today (Sutherland, 2002).

Through the 1960s, Mary Pat Murray included manual goniometric measurements in her research. Following this, the Karpovich brothers created accurate, inexpensive and simple electrogoniometers, which eased the painstaking manual task and minimized the time of data processing drastically (Sutherland, 2002). The Vanguard Motion Analyzer was the next step in ease and accuracy of motion analysis. This system was noted for its ability for projection of movie film on backlit screens to ease frame-by-frame viewing, and measurements using x and y coordinates. In 1965, Ray Linder published a description of a method to measure yaw, pitch, and roll with a two-dimensional coordinate system such as this (Sutherland, 2002). After the computer entered the picture as an aid to analyze data quickly, the VICON system, a fully automated motion capture system was created; simplifying the data collection and analyses, as well as minimizing the time spent analyzing (Sutherland, 2002). Another system, ELITE, was created with the aid of Italian researchers Ferrigno, Pedotti and Cappozzo, which was able to combine kinematics, kinetics and electromyography as a well-rounded approach to analyze gait and motion in general (Sutherland, 2002).

2.2.1 Shot Kinematics

Research examining the use of the hockey stick has been limited in the past, mainly focusing on shooting tasks and ignoring other skills such as stick handling and passing. SS and WS are seen most extensively in research, while the snap and backhand shots have not been studied extensively. Data from professional hockey games showed that the defensemen take the most SS, while centres take the least (presented in figure 2) (Montgomery et al., 2004). With regard to WS, Montgomery et al. (2004) calculated that centres use wrist shots 29% of the time, wingers perform the shot 37% of the time, while defence uses it the least, at 23% of the time. It may be such a popular shot due to it is increased level of accuracy and quickness of execution.

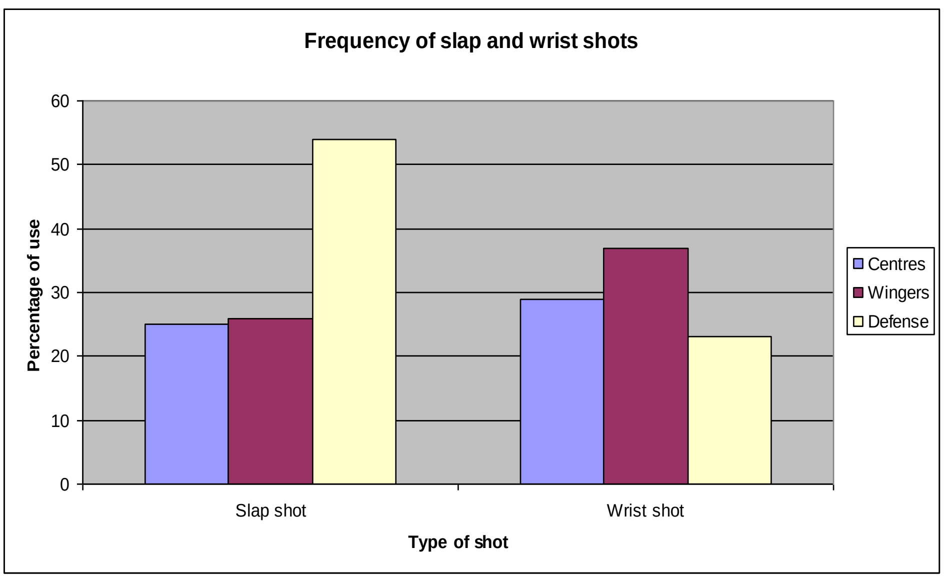

Figure 2: Frequency of Slap Shots and Wrist Shots (adapted from Montgomery et al, 2004).

Initial analyses of the SS were qualitative in nature. For example, Hayes' 1964 analysis of slap shots outlined the basic preparation and technique for the proper execution of the shot. Trunk rotation initiates the shot, followed by stick rotation where the top hand drops close to the knee, and the bottom hand moves up to the shoulder, a weight transfer from the back leg to the front leg, followed by a wrist snap where the top hand moves into extension and supination and bottom hand moves in to flexion and pronation (Hayes, 1964).

The stick is drawn back then accelerates swiftly until the blade of the stick interacts with the ice surface, 4 to 6 inches (10.14 to 15.24 cm) behind the puck. At loading time, Goktepe et al. (2010) observed through photogrammetric analysis of the dynamic SS in Turkish hockey players that mean elbow angle was 144° ± 8 °. At puck contact, the shaft of the stick has a significant amount of bend and the blade opens, which in turn causes the forearm and hand to supinate. Following this action, the shaft straightens from the pronation of the forearm, and then the blade closes, leading to shot termination. At this point, the elbow angle increases to 158° ± 5° (Goptke 2010). The hands are placed 0.4 to 0.6 m apart (Wu et al, 2003). In the standing SS, the puck is forcibly brought forward with a slapping motion, where the puck is only in contact with the blade of the stick momentarily. Deviating from the standing SS, the player is moving in a forward direction at the time of puck contact in a skating SS (Hoerner 1989). Emmert (1984) qualitatively described three phases involved in the SS, being the preparatory phase (backswing), action phase (downswing, preload, load, and release) and follow through. Although he suggested that 25% of the slap shot motion is attributed to trunk involvement, 40 to 45% to shoulder involvement and between 30 and 35% to the elbow and wrist, and upper body specific strength conditioning programs should be introduced to increase performance, no data has been presented in this study to support these hypotheses (Emmert 1984).

The SS was also described by Lomond and associates in a three-dimensional analysis of the blade contact (2007), and was similar to Emmert's paper by dividing the SS into three phases. The phases are aptly named to better describe the events associated with the blade of the stick during the shot instead of relating the events to the body's movements. They include toe-to heel contact, stick loading and blade-ground contact.

The elite hockey player initiates the slap shot by rotating the trunk followed by the pelvis. The lead shoulder then horizontally abducts while the trailing shoulder incurs vertical adduction. The lead shoulder vertically adducts, while the last movement of the shoulder is horizontal adduction of the trailing shoulder. Within the forearms, the lead elbow flexes, and lastly, the trailing elbow extends (Woo, 2004). In contrast, the recreational player begins the SS with a trailing shoulder vertical adduction, trailing elbow extension and lead shoulder vertical adduction. The trunk then begins its rotation, followed by leading elbow flexion, lead shoulder horizontal adduction and pelvic rotation. The last movement is from the trailing shoulder which produces a horizontal adduction (Woo, 2004). Additionally, Woo acknowledges that these movements influence the way the stick is manoeuvred in space. In figure 3 below, Woo (2004) illustrates the difference in blade velocity, and the angular and linear velocities between these two groups of shooters. The translational component of blade velocity is a large factor, which ultimately affects the puck speed as well.

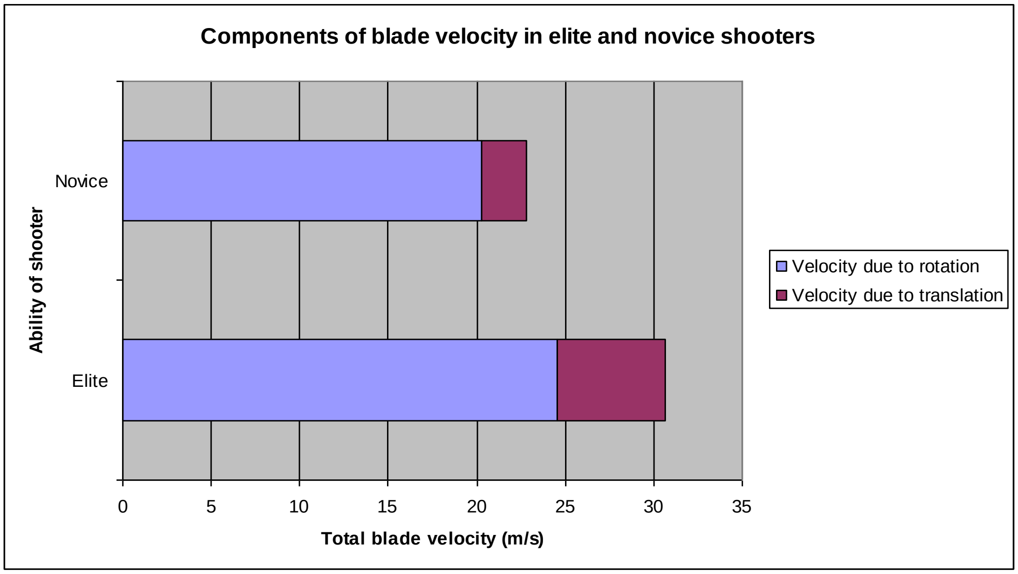

Figure 3: A representation of blade velocity illustrates the differences in the elite and recreational shooters when looking specifically at blade velocity (adapted from Woo et al, 2004)

When Lomond (2007) studied the differences of blade contact with respect to player skill, additional variations between elite and novice shooters were noted. The elite players had a significantly shorter toe to heel contact and stick loading phase and significantly longer blade-ground contact phase than that of recreational shooters. Also, there was a significant difference seen in minimum loft angle, minimum tilt angle and the maximum loft angle, as well as the overall range of global angles of the blade of the stick. Additionally, the puck velocity was measured at 73.7 ± 13.6 m/s in the elite group while it averaged 66.9 ± 14.9 m/s for the recreational group. The final displacement of the stick was significantly higher in the elite group (1.41 ± 0.21 m) than in the recreational group(1.26 ± 0.17 m), and the total range of blade excursion also differed significantly in the elite group (1.18 ± 0.39 m) versus the recreational group (0.99 ± 0.27 m) (Lomond, 2004).

Pan, Campbell, Richards, Bartolozzi, Ciccotti, and Snyder-Mackler (1998) confirmed observations similar to what Emmert (1984) had proposed. Increased puck speed in the SS by 10.43 ± 0.35 mph (16.79 ± 0.56 km/h) was noted after collegiate hockey players participated in a specialized upper extremity strength training program, emphasizing the muscle groups involved at the point of puck contact; the latissimus dorsi, anterior deltoid, triceps, wrist extensors and flexors on the dominant arm, and the trapesius, biceps, triceps, and wrist flexors (Pan et al, 1998).

2.2.2 Wrist Shot Kinematics

WS initiation begins with a drawing back of the puck using the posterior portion of the blade followed by a rapid sweep motion forward using the anterior blade portion of the stick to contact the puck. Hoerner (1989) described this motion as a ‘snap’. The snap, plus the follow through, were believed to account for the maximum velocity of the puck. Shot termination ends with a quick pronation of the lower hand moving forward, and a backwards motion of the upper hand. Wu et al. (2003) noted that the hand placement is closer than that of a SS, at 0.15 to 0.3 m apart. The orientation of the puck and blade do not change when performing a standing WS versus a skating WS (Hoerner, 1989).

An interesting study by Michaud-Paquette et al. (2008) established some factors that may affect the accuracy of WSs. Four targets, two low named bottom contralateral (BC) and bottom ipsilateral (BI), and two high, named top contralateral (TC and top ipsilateral (TI) within the net were created. It was determined that the overall accuracy on the bottom targets was 65%, while only 45% on the top two targets, possibly due to the effect of gravity and skill complexity on the higher targets (Michaud-Paquette et al, 2008). Accuracy was shown to depend on the bend of the hockey stick shaft, presumably to store and release elastic energy, thus increasing the puck speed. Greater shaft bend led to a greater ‘flick’ motion. The flick is defined as the fast change in the puck-blade orientation with the simultaneous bend recoil of the shaft. Greater flick was shown to be a predictor of an accurate shot, especially with the top corner targets (Michaud-Paquette et al., 2008). A recurring theme in several instances was the change in yaw, pitch, and roll angles of the blade and the correspondence to high accuracy (Michaud-Paquette et al., 2008). Finally, Michaud-Paquette et al. (2008) described that a more linear swing motion during contact allowed for better guidance of the puck towards the intended target, as seen in golf putting studies by Delay et al. (1997) and again in Shimizu et al. (2009).

2.2.3 Base of Support

There are several fundamental features of human posture and movement analysis that must be considered when studying a specific movement task. This includes a stable base of support. Generally, a wider base of support is recommended for these tasks because the mean force required to destabilize a subject over a task is smaller than with a narrower base of support (Delisle et al., 1998). Mathiyakom and McNitt-Gray (2008) suggest that the interaction between the environment, neurological and musculoskeletal systems allows the ground reaction forces to be generated to maintain and recover balance appropriately. The lower limbs have two main mechanical functions including postural stabilization and weight transfer.

A study involving the open and square stance of the tennis forehand by Bahamonde and Knudson (2003) showed that the base of support does not affect the interactions of the kinetic chain through the swing and that there were no significant differences seen between the open and neutral stances of the swing. Therefore, having a wider stance is more beneficial, if only for stability. In the sport of ice hockey, an additional barrier to stability is present; the low friction ice. Alpini and associates (2008) explained that hockey players, being in a unique environment, face additional challenges due to the lack of friction to aid in stability.

Weight transfer has been noted in studies on various sports, including golf, where Milburn (1982) highlighted that weight transfer is an important mechanism for the summation of the accelerations of the segments of the body beginning in the legs, moving up through the trunk to the upper limbs resulting in optimization of speed and trajectory of the projectile. Magee (2009) speculated that the forward momentum of the body generated by the transfer of weight in an ice hockey wrist shot contributes to the velocity of the puck.

During the drive off the front foot when batting in cricket, a delayed forward movement of the forward foot is visible (Stretch et al., 1998). It is assumed that this is a mechanism to allow for additional ball flight information and leads to a more accurate final decision in terms of the batter's choice of the type of stroke (Stretch et al., 1998). Delaying the shift of body weight to the forward foot in hockey, may allow for additional time to make judgments on the characteristics of the shot about to be executed as well.

2.2.4 Influence of the upper limb

Minetti (2004) explained that a combination of movements of various body segments establishes the path of the stick in ice hockey, and ultimately, the trajectory of the puck. It has been hypothesized in the past that more skilled athletes tend to vary less with their movements, increasing consistency; however, more current research such as Button et al.'s (2003) study on basketball skills contradicted this belief. For example, higher skilled basketball players had increased wrist and elbow involvement and increase movement constraint at the shoulder during a basketball free throw (Button et al., 2003). A recent kinematic analysis confirmed these findings, wherein, hockey WS were taken by high and low accuracy shooting groups. For the highly accurate, the lead shoulder was more adducted with a low range of standard deviation while more distally, at the elbow and wrist the variation was more widespread (Magee, 2009).

Grip may be another important factor in determining the ability to manoeuvre the hockey stick itself. Blackwell et al. (1999) illustrated this noting that because the stick shaft is generally consistent in circumference, it does not allow for different muscle lengths of finger flexor muscles. Lehman suggested that a wider grip elicits greater activity in muscles of the upper body than that of a narrower grip (2005). With this knowledge it is possible to modify muscle recruitment of a task by changing the position of the hands, potentially leading to better force production along specific areas of the hockey stick shaft, presumably leading to a faster shot.

2. 3 Beam Theory

Humans have always been interested in increasing their natural capabilities. To increase performance, specifically in sports, passive tools are implemented to enhance the natural abilities and compensate for limitations of the human body (Minetti, 2004). A passive tool such as the hockey stick, adds no mechanical energy to the system; however the hockey stick serves as an object which stores and releases elastic energy and amplifies the power of the shot taken when the stick is bent (Minetti, 2004).

Deflections are naturally occurring events along a beam structure such as a hockey stick. When a load is applied to the structure it deforms. This loading, for example, from the impact between a hockey stick and puck, has equal and opposite impulse forces that are exerted between the bodies deforming their shapes (Hibbiler, 2007). Castigliano's Theorem is a simple approach to further understand how deformation occurs from a load applied to a beam. It states "when forces act on elastic systems subject to small displacements, the displacement corresponding to any force, collinear with the force is equal to the partial derivative of the total strain energy with respect to that force" and the corresponding equation can be seen below (Eq. 1),

$$\delta_i = \frac{\partial v}{\partial F_1} \qquad \text{(Eq.1)}$$

where ∂_i is the displacement at the point of application of the force F_1, in direction of F1 (Budynos & Norbett, 2006, p 201).

Hodges (2000) named six distinct variables that are responsible for static strain energy and include: stretch, transverse shear in two directions, torsion and bending in two directions. For a dynamic analysis, fatigue and inertia must also be taken into account. The following equation takes these factors into account and applies them to Castigliano's Theorem, where a double integration of the equation is needed. This equation is seen below in Eq.2,

$$\frac{d^2 v}{dx^2} = \frac{M}{EI} \qquad \text{(Eq.2)}$$

where $\frac{dv}{dx} = 0$ relative to the length of the beam in the x axis, M is the moment of the beam, E is the modulus of elasticity, I is the inertia about the axis, and v is the deflection of the beam, which gives the slope as a function of x, and equation for the elastic curve Budynos & Norbett, 2006). By acknowledging these equations, it is clear that there are a number of variables which lead to deformation, and equally numerous ways of manipulating the variables to obtain the desired degree of deformation. One way to measure this deformation is through the use of strain gauges.

2. 3.1 Beam Theory and Hockey Stick Flex

Hockey sticks can be thought of as a type of beam; however, it is difficult to compare different sticks as there is no industrial standard to quantify the stiffness of the shaft (Pearsall & Turcotte, 2007). Usually, stiffness is tested by using a 3 point bend with a central and/or cantilever loading protocol. The amount of bend along the major axis is then measured to determine the stiffness of the hockey stick (Pearsall & Turcotte, 2007). The more bend the shaft has during these tests, the less stiff the shaft. This test is similar to the conditions of a hockey shot where the upper hand and point of ground contact act as constraints while the force is being applied at the lower hand (Bigford and Smith, 2009). MacKenzie and Sprigings (2009) noted in a golf study that club shaft stiffness can influence the ball flight in two ways. First, the shaft's ability to store and release strain energy, possibly resulting in an increased club head speed and second, altering the orientation of the club head relative to the ball at impact.

Bending occurs when there are two off-axis forces being applied where a tension stress is caused on one side of the system and a compression stress on the opposing side (McLester & St. Pierre, 2008). It creates what is called a bending moment along the length of the beam. Mathematically, where the force is applied, the internal sheer and bend-moment functions or slope of the function is discontinuous, meaning that the point of force application is the point with the largest magnitude of bend, as seen in figures 4 through 6 below (Hibbiler, 2007).

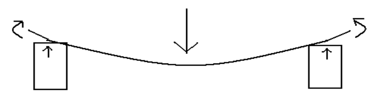

Figure 4: a three point bend test illustrates the bending moments created by the opposing forces (adapted from Hibbiler, 2007).

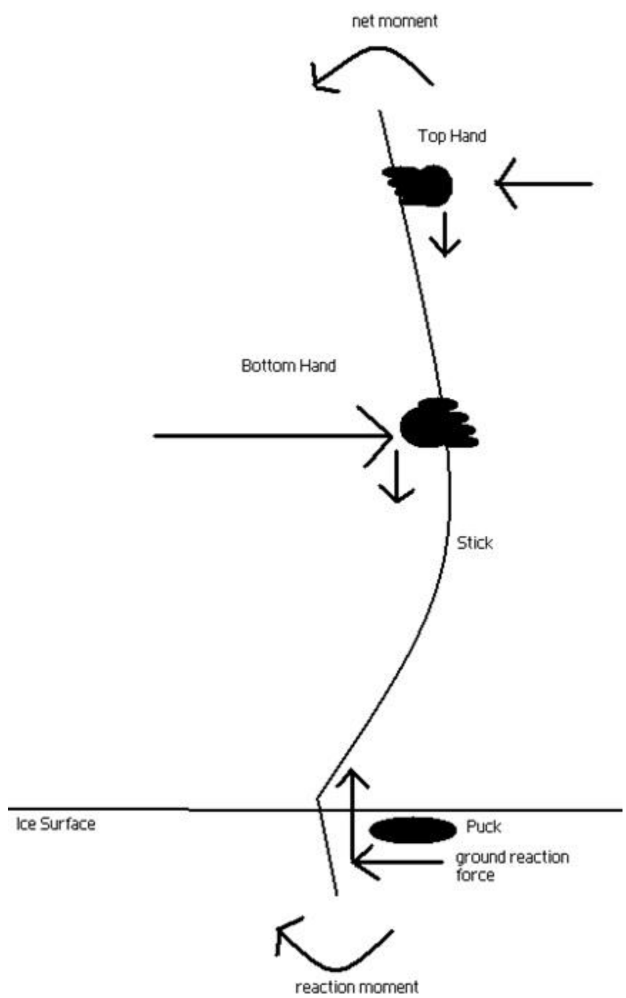

Figure 5: Example of 3 point bend applied to a hockey stick at contact with ice surface (Adapted from Hibbiler, 2007).

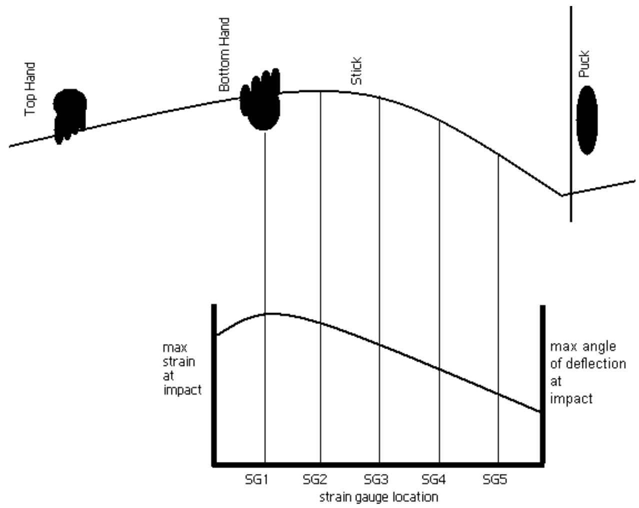

Figure 6: Typical strain profile at 5 strain gauge locations during maximum deflection during impact with surface

Although, it is essential to clarify that the puck velocity is not directly related to the maximum force a player can produce with the stick, Doré and Roy (1973) have shown that the flexion of the hockey stick shaft accounts for 10% to 35% of the puck velocity while the torsion accounts for somewhere between 23% and 28% of puck velocity (Doré and Roy, 1973).

Continuing to investigate flexion properties, Pearsall et al, (1999) evaluated six elite male hockey players performing SSs with four different sticks, each with a different shaft stiffness, being 13 KN m^{-1},16 KN m^{-1}, 17 KN m^{-1}, and 19 KN m^{-1}, representing the various levels of shaft stiffness available to ice hockey players. Surprisingly, the only significance seen with respect to an increase in puck velocity based on shaft stiffness was at 13 KN m^{-1} where the velocity was 108.2 km h^{-1} compared to the 17 KN m^{-1} stiff shafts with a velocity of 105.9 km h^{-1}. A study by Worobets, Fairbairn, & Stefanyshyn (2006) noted that shaft stiffness did not significantly affect puck velocity when performing a SS. The results of a study by Wu et al, (2003), also yielded no significant differences between stick model or type and its effects on puck speed.

The peak shaft deflection as well as the time to peak shaft deflection was shown to be statistically significant across shaft stiffness and subjects. The stick with a stiffness of 13 KN m^{-1} deflected significantly more than the others, while sticks with a 17 KN m^{-1} and 19 KN m^{-1} stiffness had a greater time to peak deflection than the rest of the sticks. The interaction effect of subject and stiffness was responsible for 67% of peak shaft deflection variation. The peak shaft deflection was shown to be between 18° and 22°, while the time to peak shaft deflection was between 23 and 27 ms (Pearsall et al., 1999). In addition, the variability in shot velocity was greater among subjects than across shaft stiffness, possibly explaining an adaptation effect to various shaft stiffness characteristics across shooters. One of these shaft stiffness characteristics is recoil effect. Villaseñor and colleagues (2005) examined the recoil mechanics of the hockey stick shaft, contrasting four elite and five recreational players' SSs using high speed video. There were distinct differences between elite and recreational recoil effects, as seen in figure 7 below. For example, the elite group had a very strong recoil phase while the recreational players had only minimal recoil.

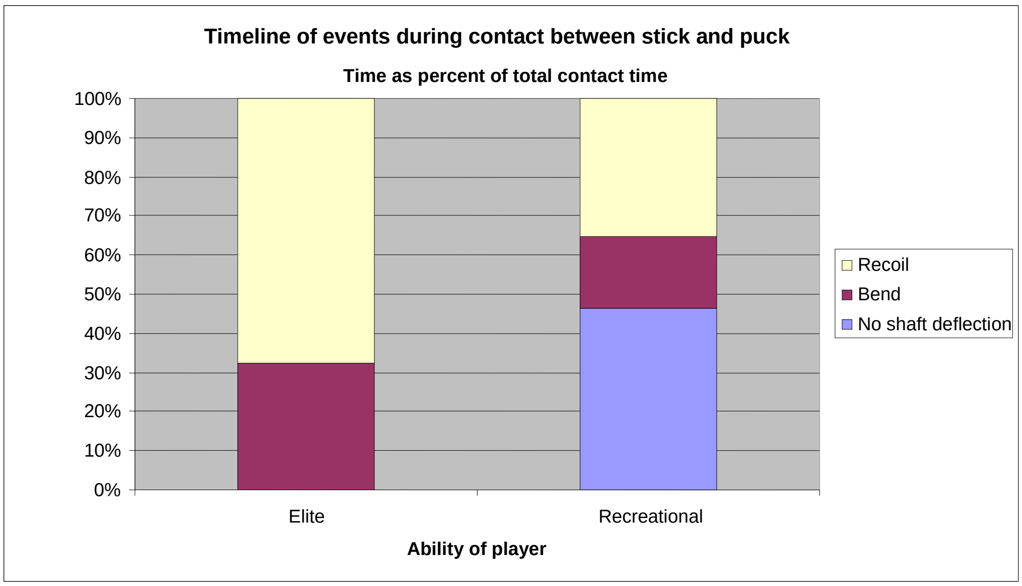

Figure 7: Visualization of the bend and recoil timeline during contact time between stick and puck (adapted Villaseñor et al., 2005).

The elite shooters had shaft bend occur shortly at or before the moment of contact until 28.8% of total blade-puck contact time, and the recoil lasted from 28.8% to 59.5% of the total period of contact between puck and blade, for a total of 88.6% of total puck-blade contact time (Villaseñor et al., 2005). In contrast, the recreational sequence showed that the bend phase began after halfway through the contact of the blade to the puck, and lasted only about 18.2%, while the subsequent recoil effect lasted until the puck-blade contact time was over (Villaseñor et al., 2005).

This recoil effect was seen in MacKenzie and Spriging's (2009) research on the stiffness of the golf club shaft and its effects on the swing. It was observed that "near impact, the dynamic forces permitted the shaft to recoil from its lagging position into a leading position" (MacKenzie & Spriging, 2009, p. 18). This phenomenon increased the relative club head velocity in relation to the most proximal location on the shaft examined. On an interesting note, in their computer simulation it was noted that the club head loft could change up to 0.7°, relative to the ball, depending on shaft stiffness. At impact, shaft stiffness influences both the launch angle and the spin rate of the ball (MacKenzie & Sprigings, 2009).

Worobets, Fairbairn, & Stefanyshyn (2006) noted that when performing the WS, the shaft stiffness accounted for half of the variability in puck velocity, where the stiffer the shaft, the slower the puck speed. It is believed that the remainder of the variability in velocity was due to biomechanical variables. The stiffer shaft was also associated with increased applied peak forces as well as a decrease in shaft deformation.

2.3.2 Strain Gauge Technology

The use of strain gauge technology has been used in the evaluation of other sports equipment publications. For example, Milne and Davis (1992) placed strain gauges along the shaft of a golf club and tested three golfers with varying handicaps ranging from eleven to five. These investigators were attempting to determine the “kick point” of golf club shafts in order to substantiate the validity of marketing claims that kick point is mechanically advantageous was valid. This is a topic that comes up often with marketing of hockey sticks as well. The kick point “refers to the shape of the bent shaft at impact” (Milne & Davis, 1992, pg. 975). Generally it is said that either the shaft is low, mid or high in kick point. Although manufacturers can construct sticks that have theoretical kick points at various points on the shaft it is not yet clear that these kick points are functionally useful during shot execution. It is thought that this also affects the “feel” of a particular club, a phenomenon that has yet to be scientifically defined but seems necessary for players to be comfortable using the equipment (Milne & Davis, 1992). Results have suggested that there was no difference between the three golfers, regardless of a difference in ability and kick point was not shown to be a useful measure of the dynamic response of the shaft during the shot. However, Milne and Davis (1992) were able to determine three phases of the swing by observing the torques measured by the strain gauges. The first phase is at the top of the swing where the shaft bends backwards. Approximately 130 ms prior to impact is the initiation of the second phase where momentum transfer takes place and the shaft gradually straightens and begins its bend forward due to the centrifugal moment at the lower end of the shaft. The third phase is at the instant of impact where some of the energy is absorbed through vibration of the shaft, while the rest is transferred to the ball. Knowing this, and taking into account each individual golfer's technique and timing, it may be possible to determine a particular shaft that will take full advantage of their own ability. This could involve changing the flexibility, kick point and feel of the shaft to best suit the player (Milne & Davis, 1992).

Magee et al. (2008) developed a portable strain gauge system to be used on hockey sticks. It had been observed that the strain data collected were able to discriminate strain by shaft location of the gauge and demonstrated temporal response and strain response discrimination in reference to the strains at different locations along the shaft. There were definite heterogeneous bending and temporal strain patterns along the shaft of the stick during the shooting task, similar to a dynamic cantilever load test. Differences were observed between the strain rates for both the SS and WS. The loading rate of strain up the shaft were similar in both shots as well as a rank order in magnitude as the highest gauge up the shaft responded the most, while the one closest to the blade responded with the smallest magnitude. The magnitude of strain was larger overall and at each individual location of the strain gauge on the shaft when comparing the SS to the WS. Additionally, the loading phase was smaller when comparing a SS to a WS (Magee et al., 2008).

The hockey stick has gone through dramatic changes over the years the game has been played. Kinematic analyses of SS and WS have been recorded throughout the years, using various techniques to describe the different shots and contrasting the technique differences by levels of play. The hockey stick is a tool which acts as a beam and goes through deformation when a shot is taken. This bend can be observed through the use of strain gauges. This bend is not uniform in nature due to the mechanical properties of the stick and potentially, by the way it is used by the shooter. Investigating the interaction between human technique and mechanical properties is warranted.

Chapter 3: Methods

3.1 Subjects

For this particular study, 17 subjects participated in the following protocol. Men aged 18 to 28 varying in skill from high to low calibre were asked to participate in this project. Subjects were all healthy and selected from the university population. Subjects were recruited from both the McGill Redmen varsity team (HC) and the university recreational hockey population (LC). Both left and right handed shooters of all playing positions were recruited. Prior to testing, an ethics certificate was obtained and subjects read and signed a consent form in accordance with the Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans. Ethical approval for this study was obtained from the McGill University's ethics committee (REB #86-0909—Appendix III).

3.2 Materials

Bauer Hockey, Corp. supplied right and left handed carbon-fibre composite sticks of the 77 flex (11.4kN/m) and 102 flex (13.9 kN/m) versions of the X60 model. These sticks were instrumented with 5 half-active Wheatstone bridges using 350Ω, 0.125 inch long strain gauges (Vishay) with an excitation voltage of 2V ± 2% along the shaft soldered to a 3.6 m long, 20 pin stranded flat cable wiring, which has been stripped of its protective covering as observed in figure 8. This minimized the extra weight of the instrumentation to the stick. Shafts were covered in shrink wrap to allow for protection and durability of the strain gauges and wiring. This covering also acted as a mask for any stick identification, with respect to flex profile, on the part of the subject, however a piece of tape with the label A or B was added for the researchers' identification purposes. Gauges were labelled SG1 through SG5, at 950mm, 750mm, 550mm, 350mm, and 150mm, respectively, from the central axis of the stick, as seen in figure 8. The strain gauge circuit was powered through a 9V (approx) power supply (Regulated Power Supply, Elenco Precision), through a 5V power bridge, as the voltage input. The strain gauge acts as a resistor. When strain is applied on the shaft of the stick, it changes the amount of voltage running through the circuit. The reduced voltage output ran through a signal conditioner (Wide Bandwidth Isolated Voltage Input, Dataforth ®) to the Data Acquisition Unit (DAQ) (NI USB-6210, National Instruments). The signal was sent through the DAQ, through a USB cable to a laptop computer.

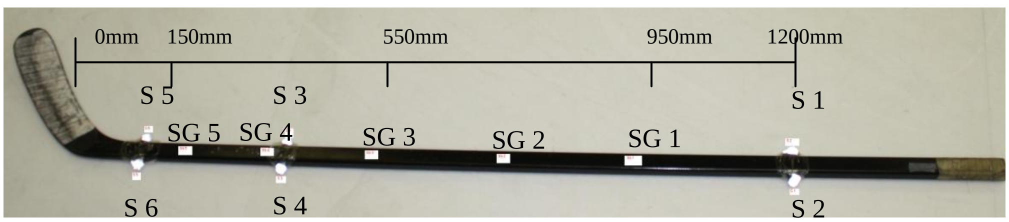

Figure 8: Instrumented stick with strain gauge placement down the centre and reflective markers on the sides of the shaft.

The blade of the stick was covered with regular white hockey tape. Passive reflective 14 mm markers were placed along the shaft of the stick at six locations, starting with the marker at the end of the shaft closest to hand placement. There were two markers on either side of the shaft on the sides of the stick at 150 mm, 400 mm and 1200 mm. They were labelled S1, the toe side marker at 1200 mm, through S6, where S6 is the 150 mm marker closest to the blade of the stick, as seen in Figure 8. Regulation pucks, each fitted with 14 mm passive reflective markers drilled into the centre of one of the puck faces, were used during the trials as seen in figure 9 below.

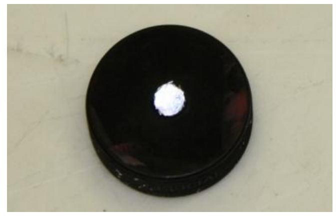

Figure 9: Puck instrumented with passive reflective marker.

The subjects’ skates were instrumented with passive reflective markers on the lateral malleoli of the skate, as in figure 10.

Figure 10: Pair of skates fitted with passive reflective markers on the lateral malleoli.

3.4 Slap and Wrist Shot Protocol

To ensure that the testing ran smoothly, it was essential to follow a pre-testing, during testing, and post-testing protocol. Calibration of sticks, collection of anthropometric and descriptive data, and calibration of the subject’s shooting arm were completed prior to testing. In addition, both during and post testing protocols are also described in detail below.

3.4.1 Calibration of Motion Capture Environment and Strain Gauges on Sticks

Prior to testing sessions, the three dimensional capture environment of eight motion capture cameras were placed in order to obtain a with a 3m x 3mx 3m capture volume. The cameras were calibrated to ensure accurate reconstruction of the marker set. This technique involved using a wand outfitted with 14 mm passive reflective markers at specific locations, provided by the manufacturer (Vicon, Inc.). The wand was waved throughout the entire capture environment in view of all of the cameras. This process was deemed successful when the dynamic calibration measures less than a 0.20 mm residual calibration error for each marker location. After this dynamic calibration procedure, a static calibration was performed in order to determine the floor plane's orientation. A 14 mm passive reflective marker L-Frame was placed in the middle of the capture volume on the floor. This procedure determined the origin of the global coordinate system and was standardized so that all subjects performed the trials within the same coordinate system.

Calibration of the strain gauges on the instrumented sticks was conducted through a shunt calibration box. This was an indirect yet accurate method of calibrating the strain gauges. Since a known voltage is going through the bridge, the calibration box lowers the resistance to various intervals, simulating the strain gauge response. This data was saved on the laptop and the calibration factor was calculated with a specific MatLab® code.

3.4.2 Pre-testing measurement

After obtaining informed consent, male shooters were asked to perform a maximum grip strength test using a hand dynamometer while the arm was in a neutral position along the side of the body while the subject remained standing. The highest value of a series of three for each hand was added together to obtain their maximum grip strength measurement value. Researchers obtained the mass of the subject using a force platform (Advanced Mechanical Technology, Inc.). Anthropometric measurements were taken for reconstruction on the subject during data processing. Elbow width, hand thickness, shoulder offset and wrist width were all measured using calipers according to the Vicon Motion Systems Plug-in-Gait Product Guide (2008). A number of 14 mm passive reflective markers were placed on their shooting (trailing) arm, and opposing hand. They were placed on the acromio-clavicular joint, the lateral epicondyle of the humerus, an offset point between those two on the upper arm, the styloid processes of both the ulna and radius, an offset point between the markers on the styloid processes and the lateral epicondyle of the humerus, and one on the centre of the dorsal side of top (trailing) hand. Additionally, a marker was placed on the hand lower (leading) hand. A calibration trial of the trail arm was captured with the Vicon MX® at 300 Hz to allow for a more accurate reconstruction of the subjects' arms.

3.4.3 Collection of Slap and Wrist Shot Trials with Subjects

A total of eight digital optical motion infrared camera (Vicon MX® system, Oxford,UK) collected data at 300 Hz to measure marker displacement. These cameras were set on tripods or fixed locations around the laboratory to ensure that the entire contact phase of the shots would be captured in the field of view. Each marker was tracked by a minimum of two cameras through the entire trial. These trials were recorded in a .c3d file and processed later. Microstrain measurements from the shaft of the stick were recorded at 20 KHz and saved as a .csv file on the laptop. Anthropometric measurements and strength were documented on a spreadsheet in Excel, for later data processing. A digital camera was used to log the trials.

The subjects were asked to warm up with his own skates on the synthetic ice surface in the biomechanics laboratory at McGill University. Once sufficiently warmed up, the shooters were asked to practice static slap and wrist shots with an instrumented stick to become comfortable with the tethered cable during the shot. Two reflective markers were then placed on the skates of the shooter at the location of their lateral malleoli. Static slap shots were taken using the instrumented stick at 3.5 m and a 90° orientation centered to net, as seen in figure 11. Three acceptable slap shot trials had been captured through the Vicon MX® and strain gauge systems simultaneously and then static wrist shots were taken until three acceptable trials has been captured. Pilot data exhibited excellent repeatability of capturing the strain data. Three shots per condition were chosen to ensure an accurate representation of the subject and the stick properties without excessive fatigue. This entire shooting protocol was repeated using the other flex variation of the stick model. The order of flex profile used in the protocol was randomized for each shooter. Participants had free choice as to their hand position during the recorded shots.

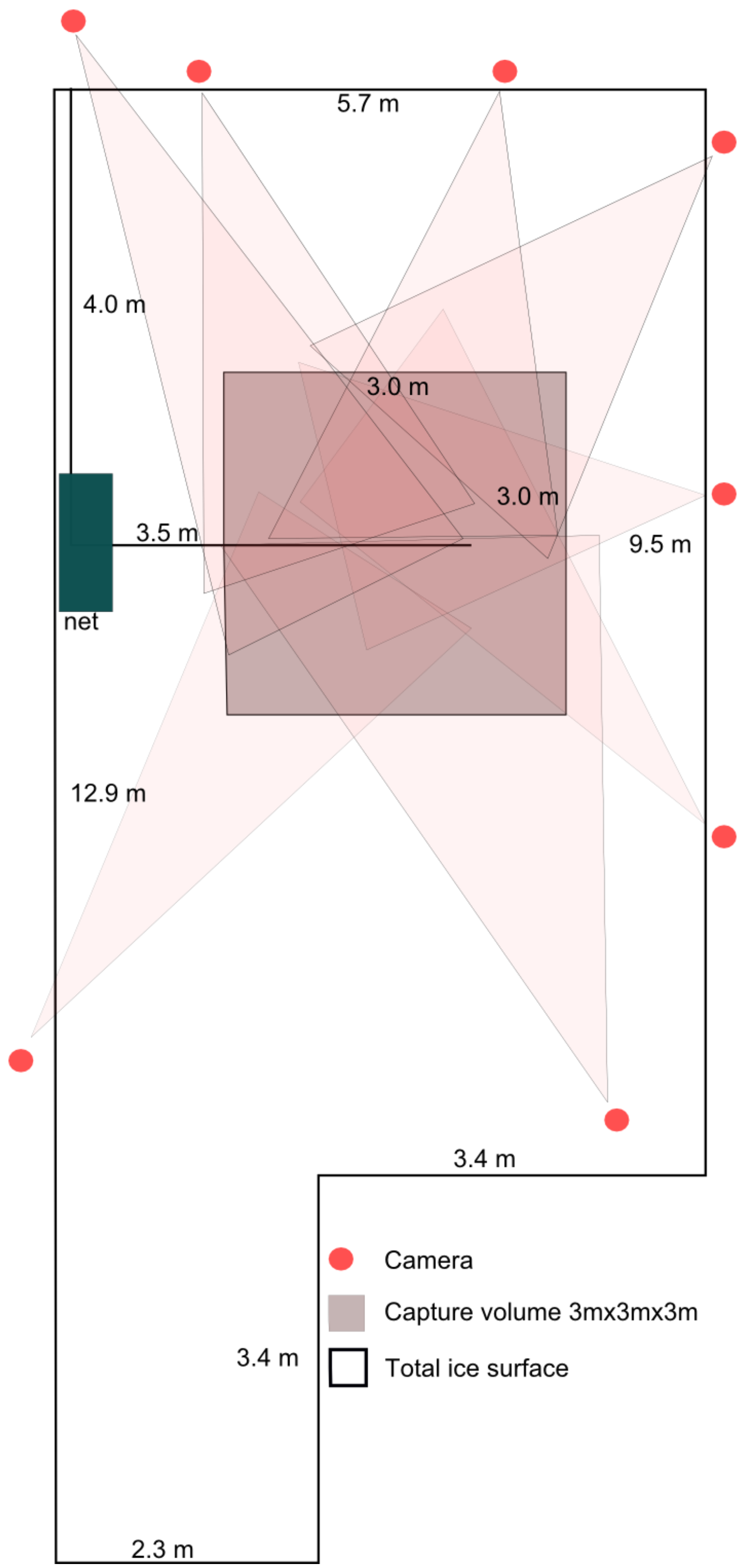

Figure 11: Experimental setup on synthetic ice surface with camera placement

3.5 Research Design

Two separate studies were conducted, one on SS and one on WS. No comparisons between shots will be made as the purpose of the shot is different. The design of each study was a 2x2 (calibre x stick type) way repeated measures experiment. The independent variables examined each have two levels as seen in Table 1 below.

Table 1: Independent variables with respective levels

Shot Type	Independent Variable	Levels
Slap shot	Calibre of player	High
		Low
	Stick Type	High flexibility (77 flex)
		Low flexibility (102 flex)
Wrist shot	Calibre of player	High
		Low
	Stick Type	High flexibility (77 flex)
		Low flexibility (102 flex)

Several dependent variables have been examined as stated in Table 2.

Table 2: Dependent variables measured during experiment

Type	Variable description	Per subject	Per group	Per stick	Per Shot
Subject Descriptive	age	value	$\bar{x} \pm SD$		
	height	value	$\bar{x} \pm SD$		
	mass	value	$\bar{x} \pm SD$		
	grip strength	value	$\bar{x} \pm SD$		

	hockey experience (level of play)		value	$\bar{x}$ ± SD		
	shooting side		value	$\bar{x}$ ± SD		
	skate brand		$\bar{x}$ ± SD	$\bar{x}$ ± SD		
Kinematics	hands	distance apart at impact with puck		$\bar{x}$ ± SD		$\bar{x}$ ± SD
	feet	distance apart at impact with puck		$\bar{x}$ ± SD		$\bar{x}$ ± SD
	puck	peak linear velocity	$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		peak linear acceleration		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
	stick	yaw of blade		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		pitch of blade		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		roll of blade		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
Stick flex dynamics	SG1	max strain		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		time to max strain		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		strain at PC		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		strain at PR		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		strain loading rate (IC to max)		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		strain decay rate (max to PR)		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
	SG2	max strain		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		time to max strain		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		strain at PC		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		strain at PR		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		strain loading rate (IC to max)		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		strain decay rate (max to PR)		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
	SG3	max strain		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		time to max strain		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		strain at PC		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD
		strain at PR		$\bar{x}$ ± SD	$\bar{x}$ ± SD	$\bar{x}$ ± SD

	strain loading rate (IC to max)	x̄ ± SD	x̄ ± SD	x̄ ± SD
	strain decay rate (max to PR)	x̄ ± SD	x̄ ± SD	x̄ ± SD
SG4	max strain	x̄ ± SD	x̄ ± SD	x̄ ± SD
	time to max strain	x̄ ± SD	x̄ ± SD	x̄ ± SD
	strain at PC	x̄ ± SD	x̄ ± SD	x̄ ± SD
	strain at PR	x̄ ± SD	x̄ ± SD	x̄ ± SD
	strain loading rate (IC to max)	x̄ ± SD	x̄ ± SD	x̄ ± SD
	strain decay rate (max to PR)	x̄ ± SD	x̄ ± SD	x̄ ± SD
SG5	max strain	x̄ ± SD	x̄ ± SD	x̄ ± SD
	time to max strain	x̄ ± SD	x̄ ± SD	x̄ ± SD
	strain at PC	x̄ ± SD	x̄ ± SD	x̄ ± SD
	strain at PR	x̄ ± SD	x̄ ± SD	x̄ ± SD
	strain loading rate (IC to max)	x̄ ± SD	x̄ ± SD	x̄ ± SD
	strain decay rate (max to PR)	x̄ ± SD	x̄ ± SD	x̄ ± SD

3.6 Data Processing

Strain data and kinematic data were initially processed separately due to different collection frequencies. Strain data was filtered with a low-pass Butterworth filter at 10 kHz with a cutoff of 200. Kinematic data was filtered using a low-pass Buterworth filter at 300 Hz with a cutoff of 8 and then upsampled to match the strain data. The data was then combined to calculate all of the previously stated variables. Using custom programming, the start of the trial was noted at the first instant that the slope of the strain at SG5 was greater than one, and the end of the trial was calculated at the point where puck acceleration was equal to zero.

The data was then cut from start to finish of the trial to make further calculations less cumbersome. Kinematics were calculated using the cross-product method with three marker positions to make a rigid segment. Maximum values were calculated with a pre-programed MatLab function and strain rates were calculated for strain loading rate at the point where initial strain at SG5 was greater than 1 to maximum strain at each gauge, and then from maximum strain until the end of the trial, where puck acceleration was equal to zero for strain decay rate.

Chapter 4: Results

The following information is a presentation of kinematic and strain data captured from seventeen subjects who performed trials across all shooting conditions. Descriptive statistics for subjects, as well as significant results at PC (puck contact), PR (puck release), and ΔPC-PR, maximum values and timing of strain response can be viewed below. Full results tables, of all variables can be viewed in Appendix IV.

4.1 Descriptive statistics

Subjects were divided into two groups (HC and LC) based on their level of competitive play experience. HC was defined as playing at a University level or higher ($n = 9$), while LC were those who play recreationally ($n = 8$). Descriptive information was collected during testing sessions. Table 3 provides a summary of this information, including x̄ and SD. In terms of body mass and grip strength the two groups were similar, though as expected HC had greater SS and WS puck velocities.

Table 3: Descriptive statistics based on calibre of player (x̄ ± SD)

Variable	HC	LC	F	*p*
Handedness (Right/Left)	4/5	5/3		
Position (Forward/Defence)	5/4	5/3		
Height (cm)	182.6 ± 2.2	174.3 ± 2.3	6.704	0.021
Mass (kg)	84.4 ± 3.7	77.4 ± 3.9	1.696	0.212
Grip Strength (N)	107.3 ± 6.4	99.8 ± 16.1	1.644	0.219
SS Velocity (m/s)	27.2 ± 4.2	22.4 ±6.6	6.126	0.019
WS Velocity (m/s)	24.2 ± 2.3	20.4 ± 2.9	17.79	0.000

4.2 MANOVA analyses

Statistics were performed using SPSS, (IBM® SPSS® Statistics, Version 18). Two 2x2 MANOVAs were conducted based on shot type. These tests allowed researchers to interpret the effects of different conditions, in this case, being the stick type and calibre of player on the many different kinematic variables. The null hypotheses are that no differences would be seen between any of the conditions aforementioned. The alternative hypotheses have been outlined above.

4.2.1 Significant MANOVA results for SS Study

Main effects ($p < .05$) were noted at PC:

- by calibre
    - elbow flexion/extension,

- SG3, SG4, SG5

(Figure 12; Table 4). Dynamic strain profiles from slap shot trials for HC and LC under both stick conditions show patterns of strain by gauge during the time of recording, as seen in Figure 12. These trials illustrate a consistent trend of bimodal maxima in SG3, SG4, and SG5. SG2 is regularly the highest peak, while SG5 is the lowest. All trials were aligned to the maximum of SG2 before ensemble averaging trials so as to preserve the waveform pattern. A slight ordered response was seen in the time to peak for all gauges in reference to SG2. No differences were seen comparing the length of deformation between calibres or sticks.

Table 4: SS significant results table by condition for PC

	Condition	$\bar{x}$	SD	n	SE	F	*p*
		Calibre					
Elbow flexion/extension at PC (°)	LC	51.0	7.1	16	1.8	10.363	0.003
	HC	40.5	11.1	18	2.6		
SG3 at PC (με)	LC	332.1	223.7	16	55.9	6.434	0.017
	HC	838.1	744.9	18	175.6		
SG4 at PC (με)	LC	214.0	134.9	16	33.7	7.702	0.009
	HC	642.2	583.6	18	137.6		
SG5 at PC (με)	LC	145.0	86.8	16	21.7	8.394	0.007
	HC	491.6	455.9	18	107.5		

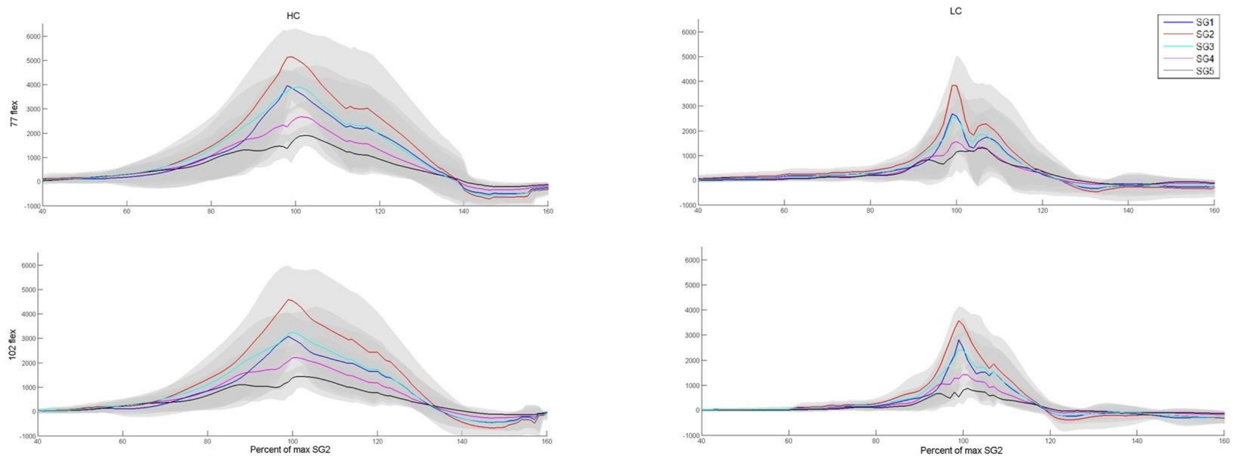

Figure 12: Average dynamic strain profiles of the slap shot by calibre (left = HC; right = LC) and stick (top = 77; bottom = 102). Trials have been focused on a smaller portion of the shooting trial in order to see the details of the peaks. The time scale has been normalized from the times of IC to max SG2.

Significant results were also noted at PR. Main effects ($p \leq .05$) were seen by calibre in elbow flexion/extension (Table 5).

Table 5: SS significant results for calibre at PR

	Condition	$\bar{x}$	SD	n	SE	F	p
	Calibre						
Elbow flexion/extension at PR (°)	LC	46.2	6.3	16	1.6	6.561	0.016
	HC	39.2	8.7	18	2.0		

Main effects ($p < .05$) were observed in calibre when looking at the change in some variables between PC and PR (i.e. Δ PC-PR), these include SG1, SG3, SG4, SG5 (Table 6).

Table 6: SS Significant results for calibre for Δ PC-PR

	Condition	$\bar{x}$	SD	n	SE	F	*p*
			Calibre				
SG1 Δ PC-PR (με)	LC	-181.3	713.1	16	178.3	5.172	0.030
	HC	-787.0	790.3	18	186.3		
SG3 Δ PC-PR (με)	LC	-134.2	738.2	16	184.5	7.269	0.011
	HC	-967.9	981.6	18	231.4		
SG4 Δ PC-PR (με)	LC	-67.0	477.4	16	119.4	7.958	0.008
	HC	-680.9	718.1	18	169.3		
SG5 Δ PC-PR (με)	LC	-57.5	311.5	16	77.9	6.820	0.014
	HC	-459.3	523.1	18	123.3		

When investigating maximum values for the variables analyzed, main effects ($p < .05$) were seen in calibre for blade pitch, SG1 to SG5 and puck velocity and when comparing sticks for SG4 and SG5 (Table 7).

Table 7: SS Significant results for calibre and stick for maximum values

	Condition	x̄	SD	n	SE	F	p
			Calibre				
Blade pitch max (°)	LC	106.8	9.1	16	2.3	5.450	0.026
	HC	100.4	6.6	18	1.6		
SG1 max (με)	LC	2774.0	878.8	16	219.7	10.509	0.003
	HC	3645.8	775.9	18	182.9		
SG2 max (με)	LC	3686.2	1432.3	16	358.1	7.257	0.011
	HC	4900.7	1171.3	18	276.1		
SG3 max (με)	LC	2596.6	761.2	16	190.3	18.852	0.000
	HC	3737.6	832.3	18	196.2		
SG4 max (με)	LC	1903.1	501.3	16	125.3	21.094	0.000
	HC	2713.0	573.0	18	135.1		
SG5 max (με)	LC	1589.9	731.5	16	182.9	4.153	0.050
	HC	1961.2	400.1	18	94.3		
Max Puck Velocity (m/s)	LC	22.4	6.6	16	1.6	6.126	0.019
	HC	27.2	4.2	18	1.0		
			Stick				
SG4 max (με)	77	2523.9	726.8	17	176.3	4.523	0.042
	102	2139.9	570.3	17	138.3		
SG5 max (με)	77	2047.2	706.7	17	171.4	8.169	0.008
	102	1525.7	317.4	17	77.0		

Maximum strain can be visualized in figure 13. SG2 provided the greatest maximum strains amongst all calibre and stick conditions. This coincides with the mean location of the hand placement for both calibres. Strains decreased substantially with the distance from SG2. At plus or minus 200 mm (SG1 and SG3) strain maxima were 20% to 32% lower. At minus 400 mm (SG4) strains were 42% to 48% lower. At minus 600 mm (SG5, closest to the blade) strains were 64% and 54% lower. In general, the 77 stick produced greater strains (7%

to 27 %) than the 102 flex, varying by gauge location and player calibre. At SG4 and SG5 the 77 vs 102 stick strains were significantly different. As well, HC players produced significantly greater strains than LC at all gauge locations.

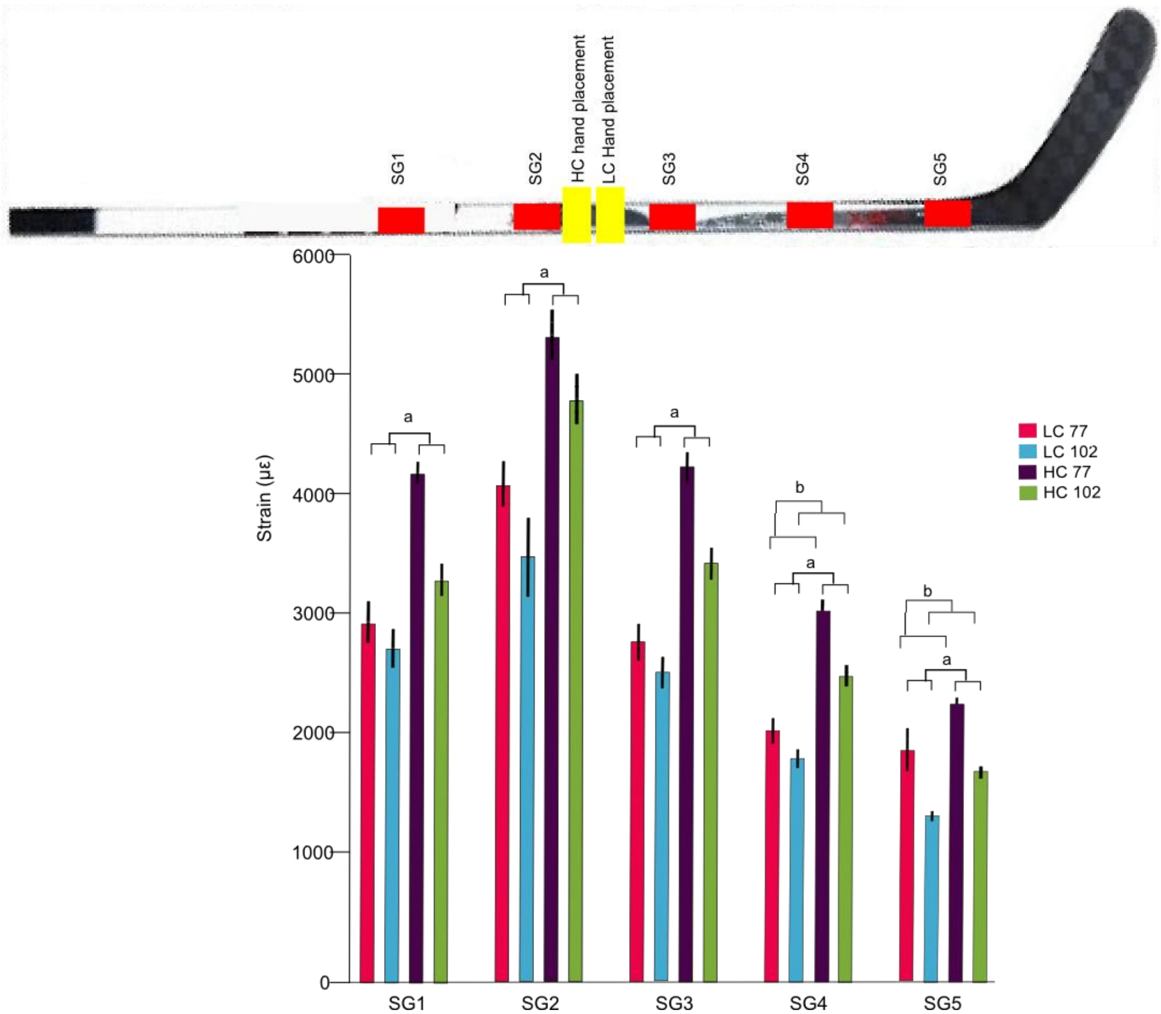

Figure 13:Maximum strains recorded during slap shot based on calibre and stick. Data are Means ±SEM. Significant differences are denoted by **a** (by calibre) and **b** (by stick). The hockey stick illustrates the approximate location of the corresponding strain gauges and average lower hand placement for both calibres.

Lastly, with regards to duration, HC and LC players completed the slap shots in 142.6 versus 429.0 ms ($p<0.001$), respectively: approximately 3 times quicker for HC. This duration may be divided into pre-puck contact (Pre-PC) and puck contact (PC) phases (Figure 14; Table 8). Pre-PC for LC is approximately 4 times longer than that of HC, while PC phase is almost 1.4 times longer. In terms of relative duration, HC shooters spend 60% / 40% of their shot time in Pre-PC and PC phases, while LC shooters spend 80% / 20% of their shot time in Pre-PC and PC phases respectively. Maximum SG2 strain occurred at approximately the 80% of shot time for LC shooters, and 30% for HC.

Furthermore, a main effect ($p \leq .05$) was seen by calibre in the time to peak strain of SG1 to SG5 (Figures 14, 15). In general, SG maxima occurred within a 2 ms window. The time to peak strain for HC was approximately 15% of the time to peak strain for LC, seen consistently across gauge locations. Similarly, a main effect ($p \leq .05$) was seen by calibre in mean loading and decay strain rates of SG1 to SG5 (Table 8; Figures 16 and 17), with HC responses being significantly greater than LC.

Table 8: SS Significant results for player calibre and stick timing values

	Condition	x̄	SD	n	SE	F	*p*
	Calibre						
SG1 time to peak strain (ms)	LC	348.0	316.2	16	79.1	14.490	0.001
	HC	53.2	40.0	18	9.4		
SG2 time to peak strain (ms)	LC	348.5	317.3	16	79.3	14.337	0.001
	HC	54.3	39.5	18	9.3		
SG3 time to peak strain (ms)	LC	349.0	317.3	16	79.3	14.210	0.001
	HC	56.2	38.9	18	9.2		
SG4 time to peak strain (ms)	LC	349.5	317.9	16	79.5	14.225	0.001
	HC	56.1	39.3	18	9.3		
SG5 time to peak strain (ms)	LC	347.1	315.4	16	78.8	14.273	0.001
	HC	55.4	38.6	18	9.1		
SG1 mean load rate IC to peak (με/ms)	LC	4.5	4.5	16	0.3	12.859	0.011
	HC	10.0	4.01	18	0.2		
SG2 mean load rate IC to peak (με/ms)	LC	6.9	5.1	16	0.3	10.235	0.003
	HC	12.9	5.7	18	0.3		
SG3 mean load rate IC to peak (με/ms)	LC	3.8	3.6	16	0.2	17.093	0.000
	HC	9.2	3.7	18	0.2		
SG4 mean load rate IC to peak (με/ms)	LC	2.8	2.6	16	0.2	18.553	0.000
	HC	6.7	2.6	18	0.1		
SG5 mean load rate IC to peak (με/ms)	LC	2.6	2.8	16	0.2	8.392	0.007
	HC	5.3	2.5	18	0.1		
SG1 mean decay rate peak to PR (με/ms)	LC	-5.7	2.1	16	0.1	11.023	0.002
	HC	-10.0	4.2	18	0.2		
SG2 mean decay rate peak to PR (με/ms)	LC	-5.4	4.9	16	0.3	15.603	0.000
	HC	-14.0	7.0	18	0.4		
SG3 mean decay rate peak to PR (με/ms)	LC	-3.5	5.9	16	0.4	15.297	0.000
	HC	-11.2	5.3	18	0.3		
SG4 mean decay rate peak to PR (με/ms)	LC	-2.0	3.5	16	0.2	16.758	0.000
	HC	-7.9	3.7	18	0.2		
SG5 mean decay rate peak to PR (με/ms)	LC	-2.6	3.9	16	0.2	7.444	0.011
	HC	-5.6	2.7	18	0.1		
Blade-ice contact from IC-PC (ms)	LC	349.3	298.8	16	74.7	10.771	0.003
	HC	84.9	136.1	18	32.1		
Shot time from IC- PR (ms)	LC	429.0	287.9	16	72.0	13.340	0.001
	HC	142.6	138.1	18	32.3		
Blade-puck contact time from PC-PR (ms)	LC	79.7	21.4	16	5.4	12.408	0.001
	HC	57.8	13.7	18	3.2		

	Stick						
SG5 mean decay rate peak to	77	-5.3	2.9	17	0.2	4.759	0.037
PR (με/ms)	102	-369.869	3.9	217797	0.2	17	5.286

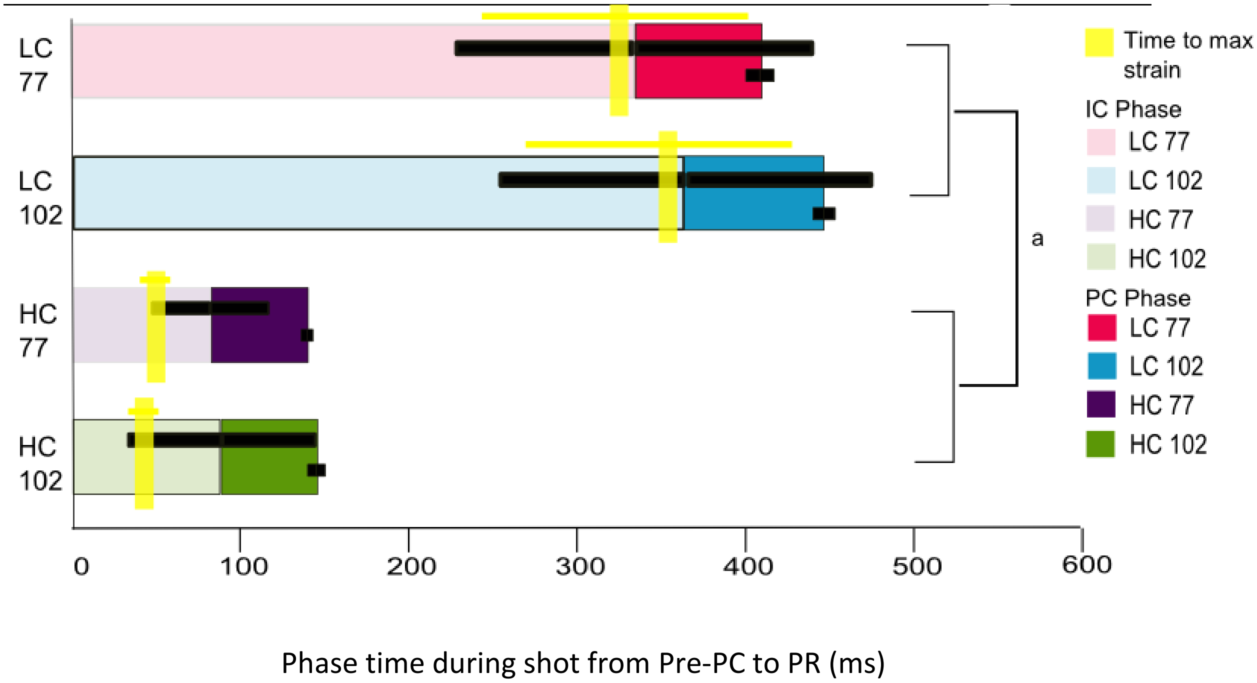

Figure 14: Ice contact and puck contact phases by stick and calibre. Data are means ± SEM for SS. Significant differences are denoted by **a** (by calibre). The vertical yellow line denotes the approximate time to maximum strain. Data are x̄ ± SEM (horizontal yellow lines) for each stick using SG2 as a reference.

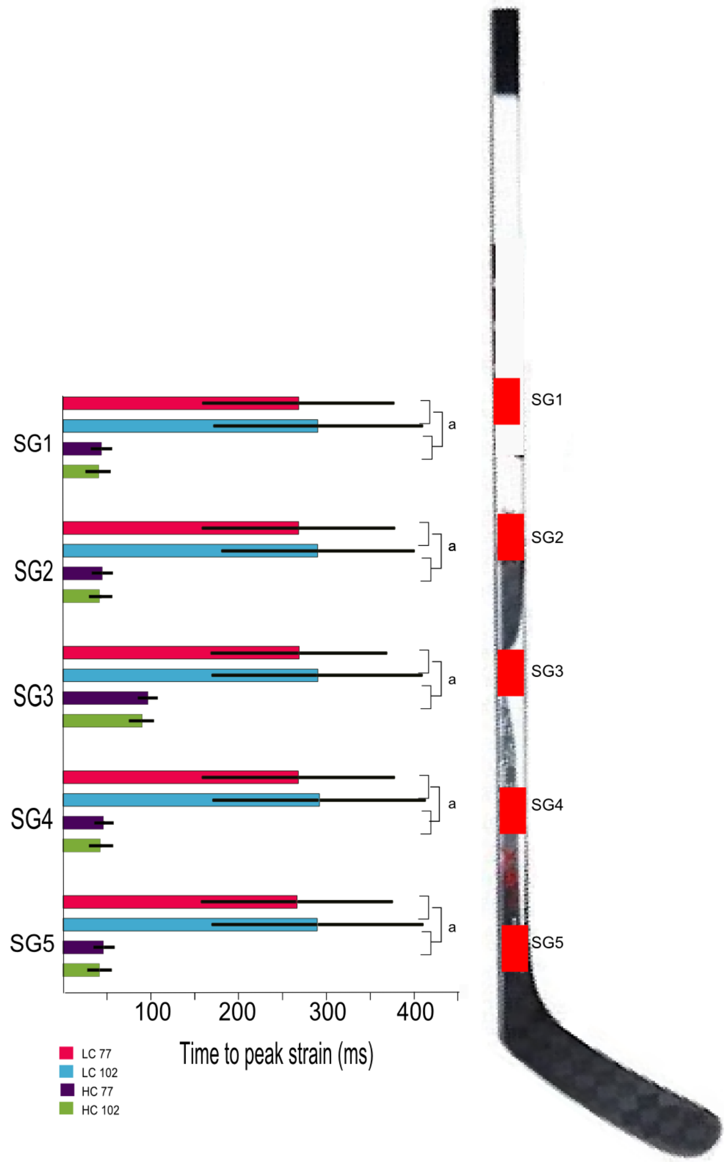

Figure 15: Time to peak strain at each gauge location for the slap shot based on calibre and stick type. Data are x̄ ± SEM. Significant differences are denoted by a (by calibre). The hockey stick illustrates the approximate location of the corresponding strain.

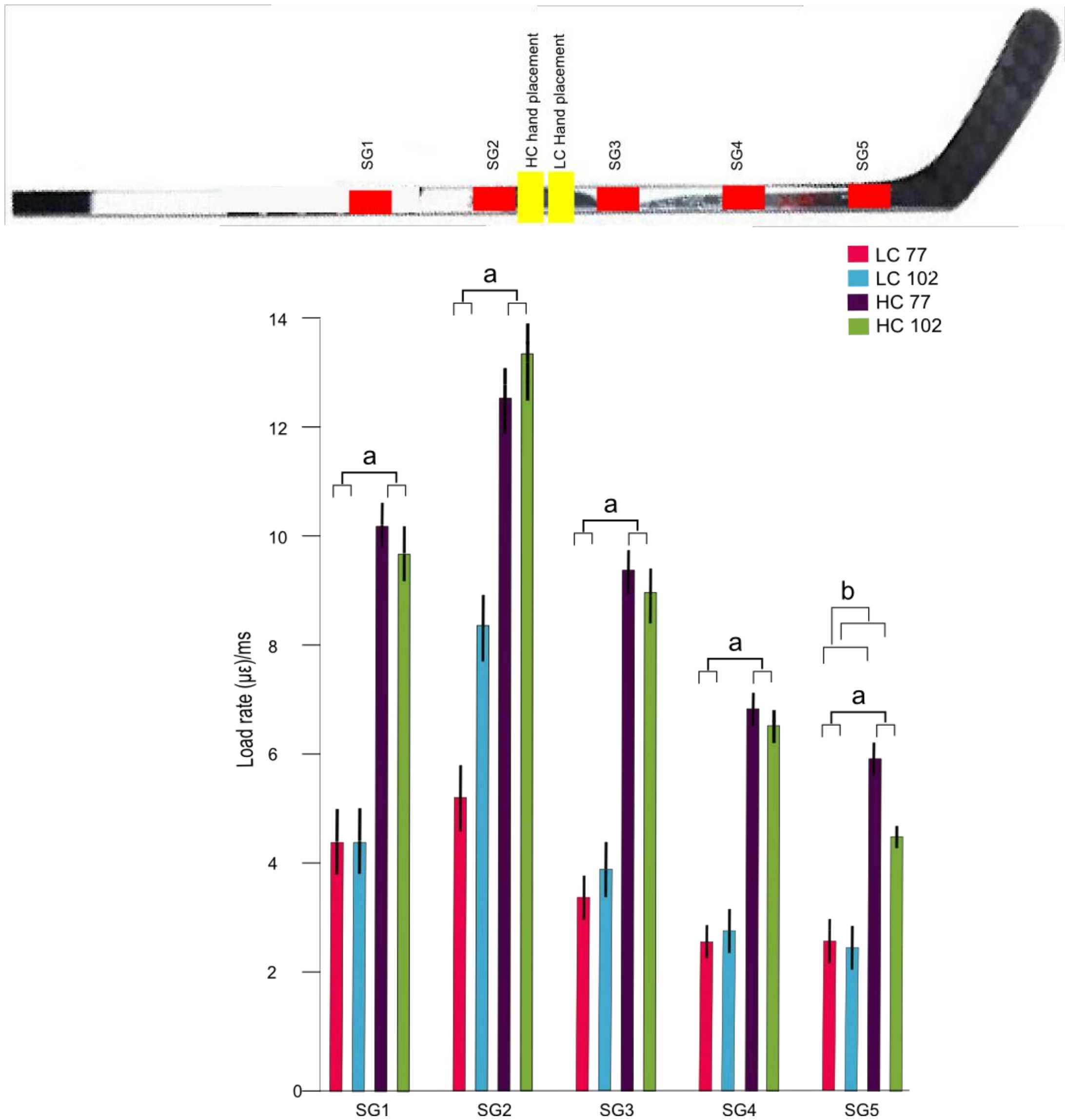

Figure 14: Strain loading rate at each gauge location for the slap shot based on calibre and stick type. Data are x̄ ± SEM. Significant differences are denoted by **a** (by calibre) and **b** (by stick). The hockey stick illustrates the approximate location of the corresponding strain.

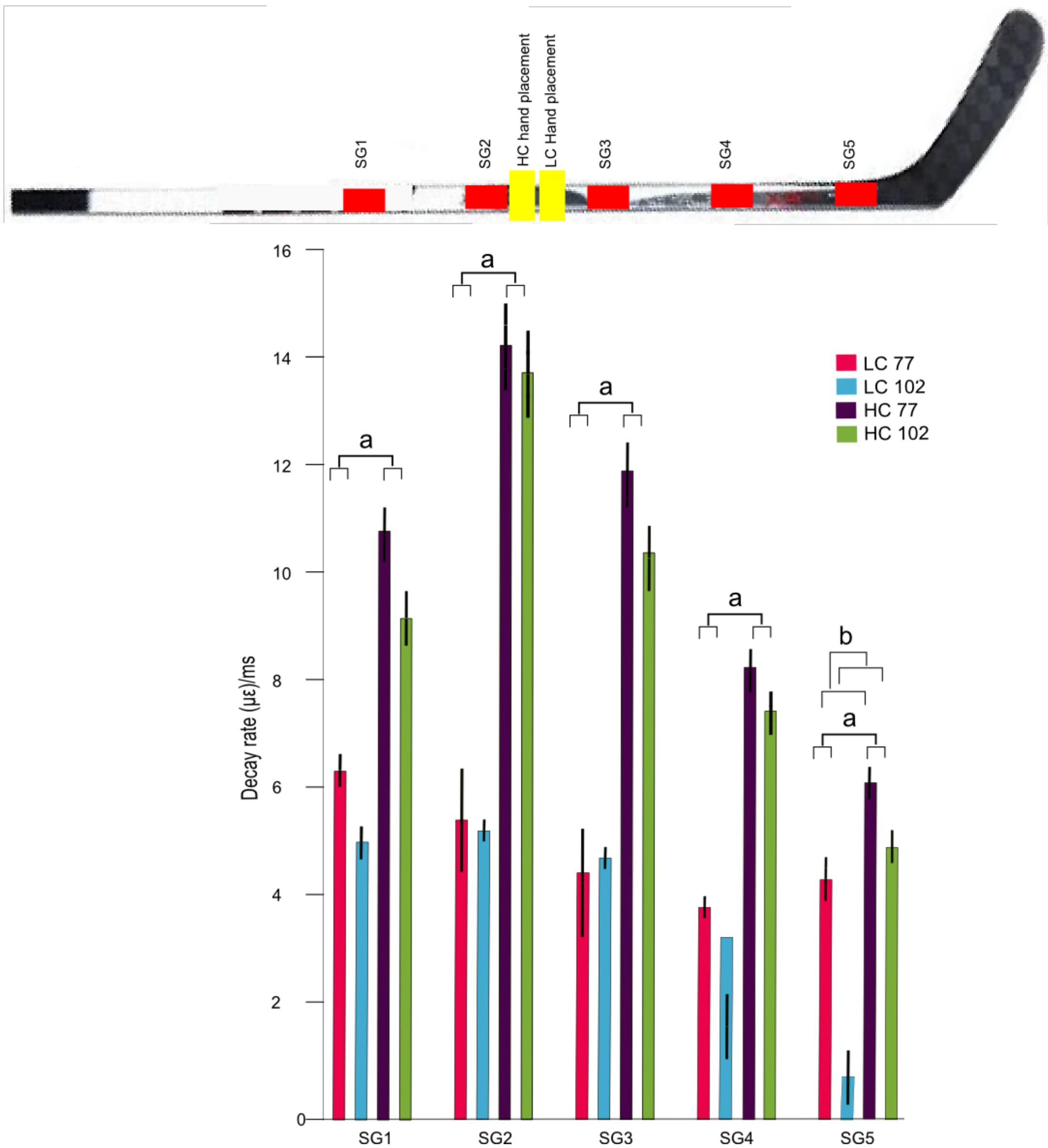

Figure 15: Strain decay rate at each gauge location for the slap shot based on calibre and stick type. Data are x̄ ± SEM. Significant differences are denoted by **a** (by calibre) and **b** (by stick). The hockey stick illustrates the approximate location of the corresponding strain.

4.2.2 Significant MANOVA results for WS study

Main effects were not seen in any variable for the time of PC. At PR a main effect ($p \leq .05$) was seen by calibre for:

- stance width,
- wrist flexion/extension

(Table 9). No differences were noted in the time of deformation between stick or calibre for the wrist shot. Between Δ PC-PR no statistically significant differences were seen.

Table 9: WS significant results for calibre and stick at PR

	Condition	x̄	SD	n	SE	F	*P*
	Calibre						
Stance width at PR (mm)	LC	760.6	142.2	16	35.5	9.343	0.005
	HC	889.8	97.5	18	23.0		
Wrist flexion/extension at PR (°)	LC	-17.8	12.1	16	3.0	5.446	0.027
	HC	-10.5	7.1	18	1.7		

In the WS condition comparing maximum values (Table 10), a main effect ($p \leq .05$) of calibre was observed for:

- with SG1, SG3, SG4, SG5,
- puck velocity.

A main effect ($p \leq .05$) of stick was observed for:

- SG1, SG3, SG4, SG5

Similar trends as seen for the SS were evident in WS mean maximum strains by calibre and stick conditions (Figures 18 and 19), though WS magnitudes were substantially lower. Typically, greatest strain corresponded to SG2 within calibre and stick conditions. Lower hand position during the shot indicated that the hands were placed between SG1 and SG2. HC shooters produced greater maximum strains than LC. In general, a rank order can be seen within conditions where each gauge further away from SG2 had sequentially lower strains (excluding SG1 for HC using the 77 flex stick). HC shooters generated lower strains (74% and 87%) with the 102 versus 77 flex sticks. LC shooters followed a similar pattern, with the 102 flex maximum strains reaching between 71% and 80% of those seen with the 77 flex (except for SG2). In general, LC produced maximum strains approximately 30% less than HC for both sticks except for SG2 were 77 flex strains were with 1 to 16% of 102 flex strains.

Table 10:WS significant results for calibre and stick maximum values

	Condition	x̄	SD	n	SE	F	*P*
		Calibre					
SG1 max (με)	LC	2229.2	657.0	16	164.3	17.002	0.000
	HC	3145.1	780.0	18	183.9		
SG3 max (με)	LC	1331.1	393.2	16	98.3	18.447	0.000
	HC	1962.6	513.2	18	121.0		
SG4 max (με)	LC	881.5	259.3	16	64.8	18.084	0.000
	HC	1305.4	344.5	18	81.2		
SG5 max (με)	LC	612.4	208.9	16	52.2	11.944	0.002
	HC	856.0	249.1	18	58.7		
Max Puck Velocity (m/s)	LC	20.4	2.9	16	0.7	17.790	0.000
	HC	24.2	2.3	18	0.5		
		Stick					
SG1 max (με)	77	3054.9	944.9	17	229.2	9.098	0.005
	102	2373.3	596.3	17	144.6		
SG3 max (με)	77	1854.5	618.7	17	150.1	6.406	0.017
	102	1476.3	420.9	17	102.1		
SG4 max (με)	77	1225.1	412.5	17	100.0	5.585	0.025
	102	986.7	289.8	17	70.3		
SG5 max (με)	77	855.7	262.9	17	63.8	10.415	0.003
	102	627.1	203.4	17	49.3		

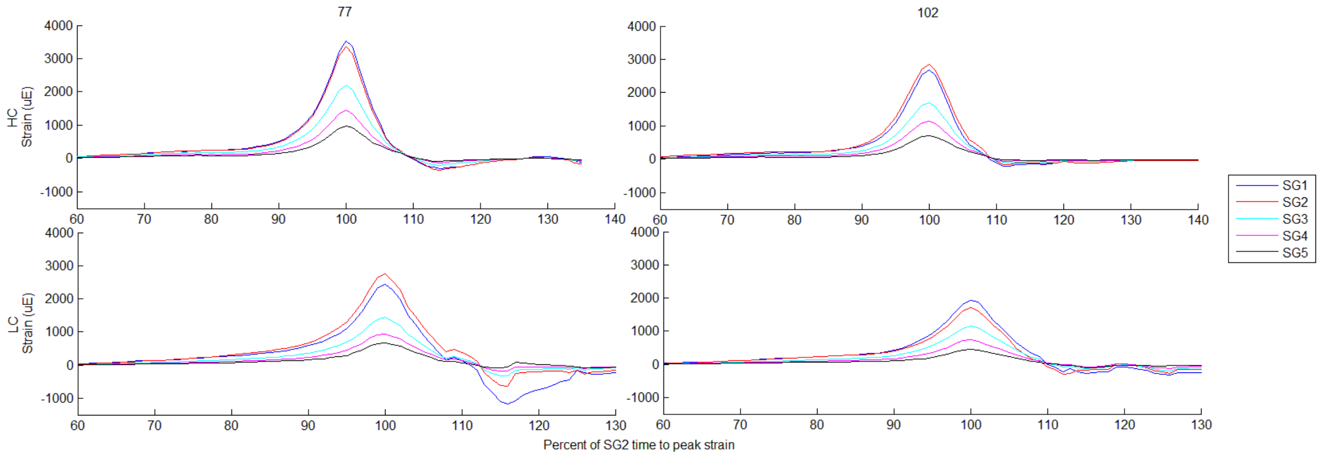

Figure 16: Average dynamic strain profiles of the wrist shot by calibre (top = HC; bottom = LC) and stick (left = 77; right = 102). Trials have been focused on a smaller portion of the shooting trial in order to see the details of the peaks. The time scale has been normalized from the times of IC to max SG2

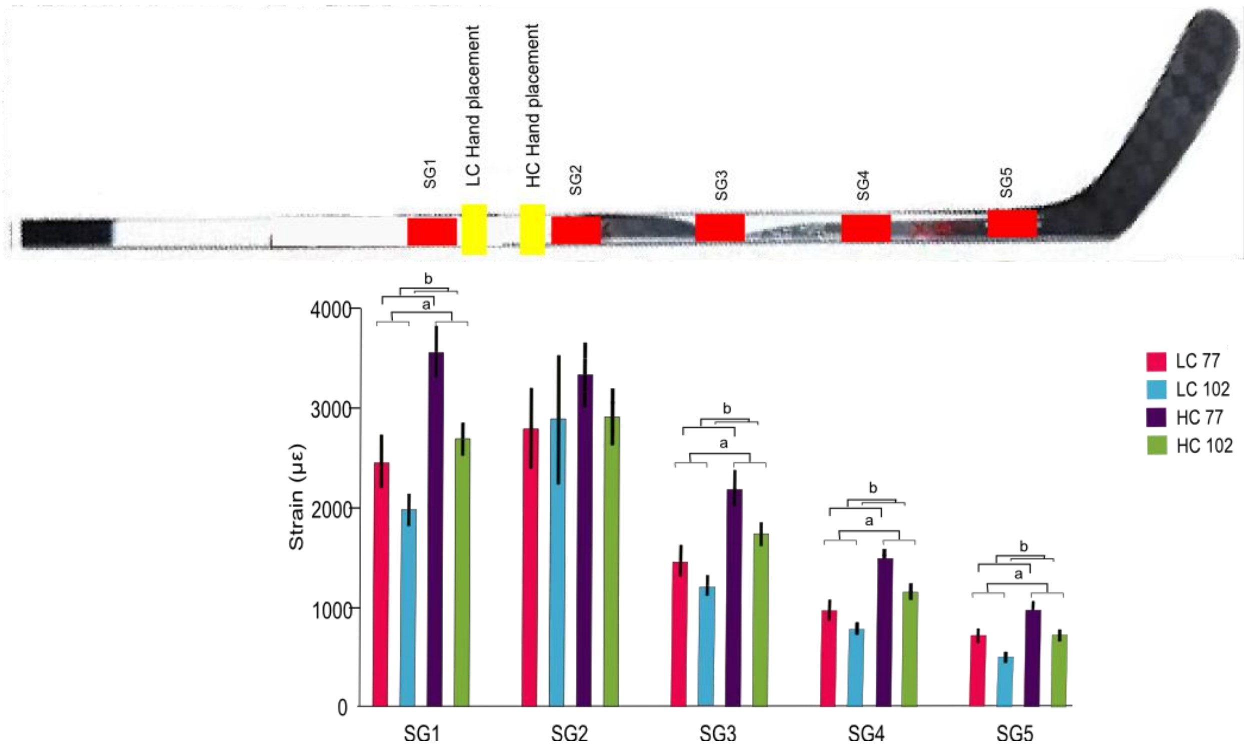

Figure 17: Maximum strains recorded during wrist shot based on calibre and stick. Data are x̄ ± SEM. Significant differences are denoted by **a** (by calibre) and **b** (by stick). The hockey stick illustrates the approximate location of the coresponding strain gauges and average lower hand placement for both calibres.

Although no differences were noted in the time to peak strain during the WS condition, there were significant differences observed in the average loading and decay rates by each strain gauge (Table 11, Figures 20, 21). In general, HC loading and decay strain rates were greater than those shown by LC. Although not significant, patterns were seen in the time to peak strain for the WS (Figure 22), where time to peak strain for the 102 flex stick when used by a HC shooter took only 85% of the time to reack the maximum strain, compared to the 77 flex stick for a HC shooter.

Table 11: WS significant results for calibre and stick timing values

	Condition	x̄	SD	n	SE	F	*P*
			Calibre				
mean load rate IC to peak (με/ms)							
SG1	LC	0.4	0.6	16	0.1	5.254	0.029
	HC	0.5	0.2	18	0.1		
SG3	LC	0.2	0.1	16	0.1	4.287	0.047
	HC	0.3	0.2	18	0.1		
mean decay rate peak to PR (με/ms)							
SG1	LC	-2.5	1.8	16	0.1	9.294	0.005
	HC	-4.9	2.9	18	0.2		
SG2	LC	-2.4	2.4	16	0.1	6.937	0.013
	HC	-4.8	3.0	18	0.2		
SG3	LC	-1.5	1.0	16	0.1	9.075	0.005
	HC	-2.9	1.8	18	0.1		
SG4	LC	-0.9	0.6	16	0.1	8.822	0.006
	HC	-1.9	1.1	18	0.1		
SG5	LC	-0.6	0.4	16	0.1	7.310	0.011
	HC	-1.2	0.7	18	0.1		
			Stick				
mean decay rate peak to PR (με/ms)							
SG1	77	-4.7	3.1	17	0.2	5.127	0.031
	102	-2.9	1.8	17	0.1		
SG2	77	-4.6	3.	17	0.2	4.278	0.047
	102	-2.8	3.0	17	0.2		
SG5	77	-1.1	0.7	17	0.1	4.989	0.033
	102	-0.7	0.5	17	0.1		

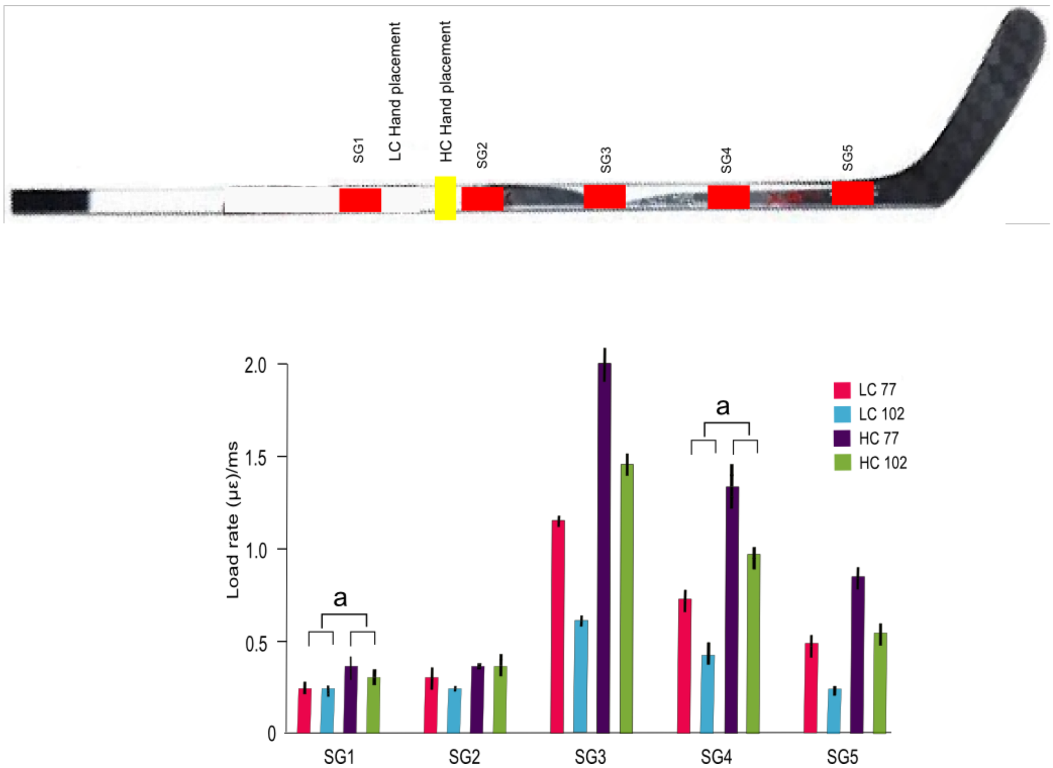

Figure 18: Strain decay rate at each gauge location for the slap shot based on calibre and stick type. Data are x̄ ± SEM. Significant differences are denoted by a (by calibre) and b (by stick). The hockey stick illustrates the approximate location of the corresponding strain.

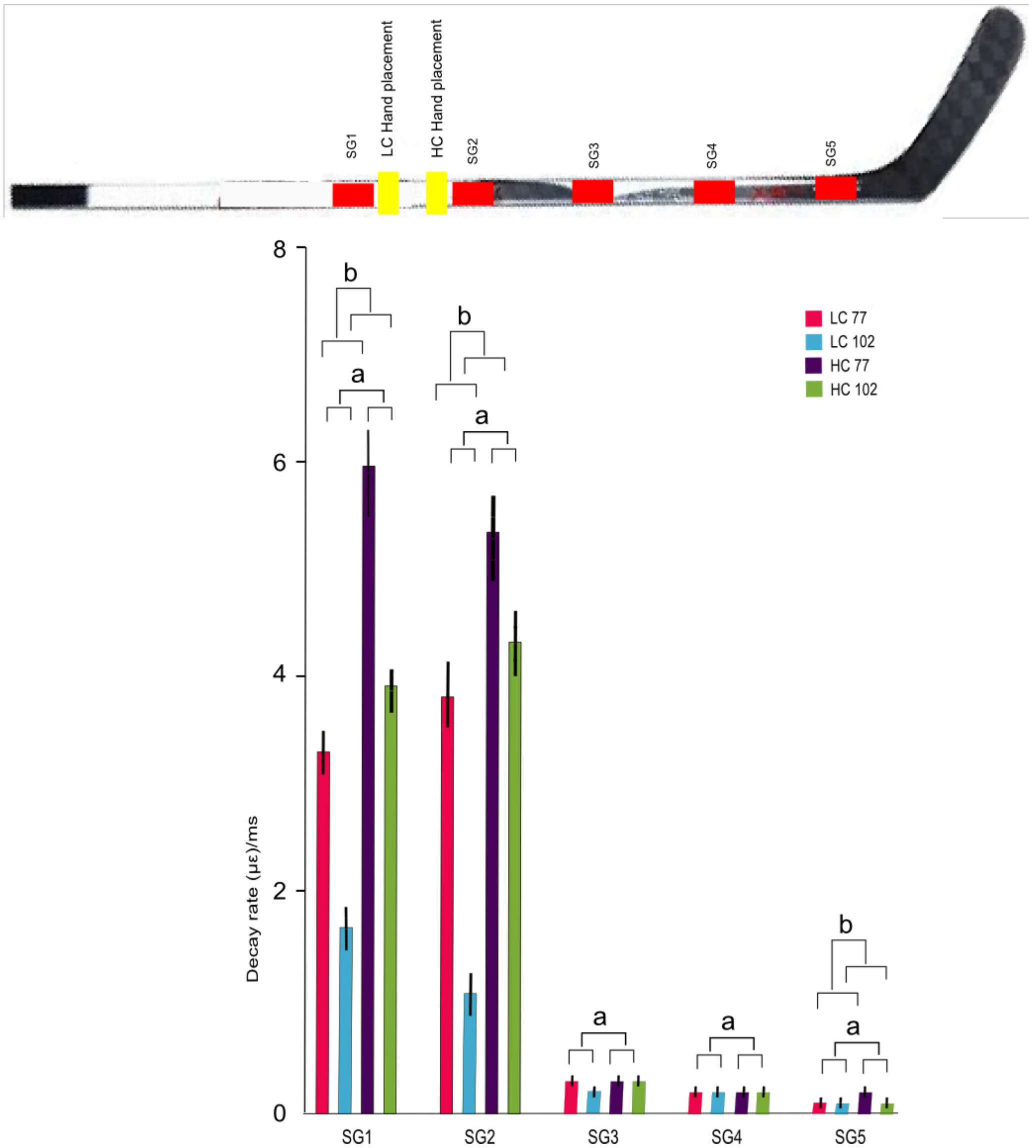

Figure 19: Strain decay rate at each gauge location for the slap shot based on calibre and stick type. Data are x̄ ± SEM. Significant differences are denoted by a (by calibre) and b (by stick). The hockey stick illustrates the approximate location of the corresponding strain.

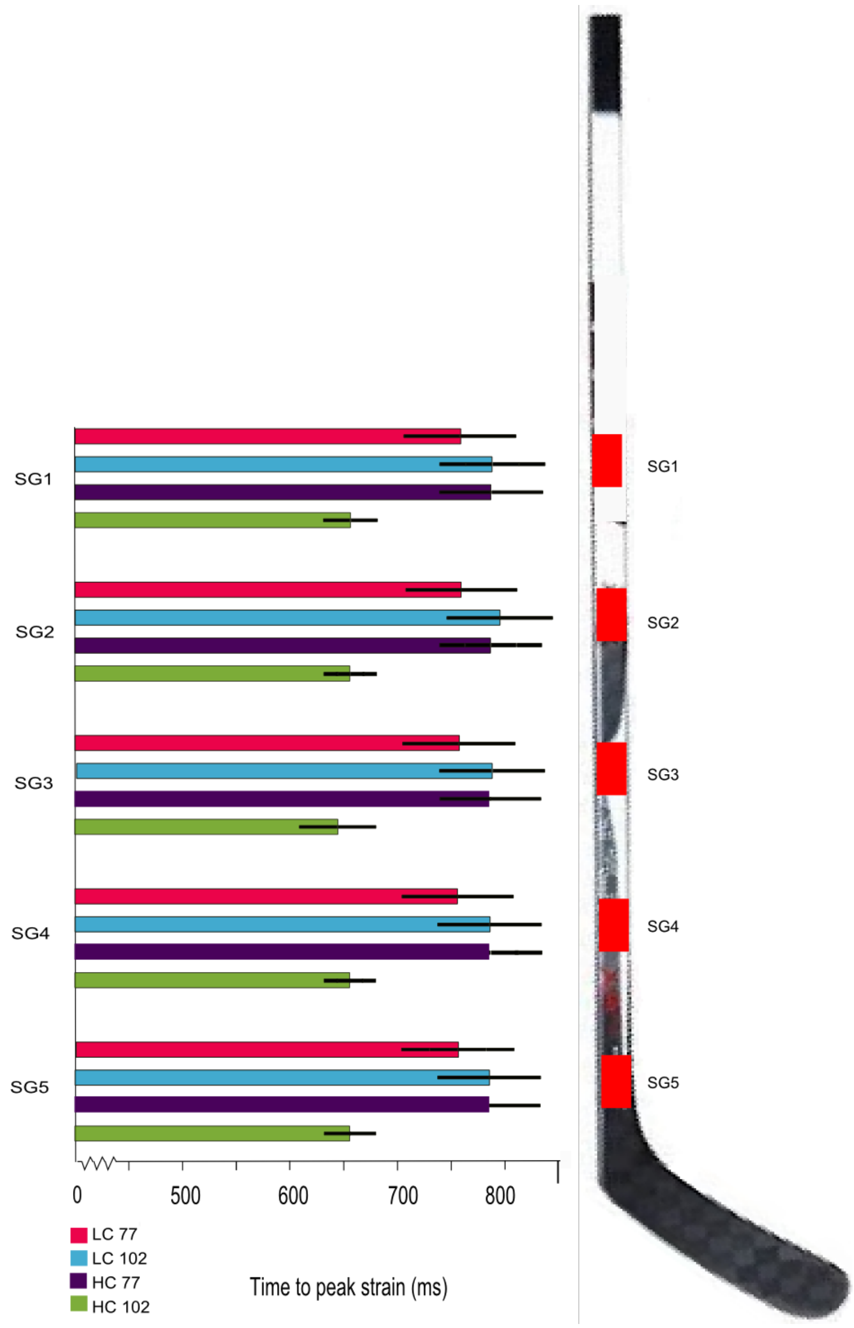

Figure 20: Time to peak strain at each gauge location for the wrist shot based on calibre and stick. Data are x̄ ± SEM. No significant differences were observed. The hockey stick illustrates the approximate location of the corresponding strain.

The phase times for Pre-PC, PC and whole shot (IC to PR) were not significantly different ($p \geq .05$), (Figure 23). Shot times were similar for all conditions. The Pre-PC phase represented 65% to 70% of the overall shot time, leaving the remain PC phase to 30% to 35%. Maximum strains occurred at approximately 50% of the PC phase, which was consistant across all conditions.

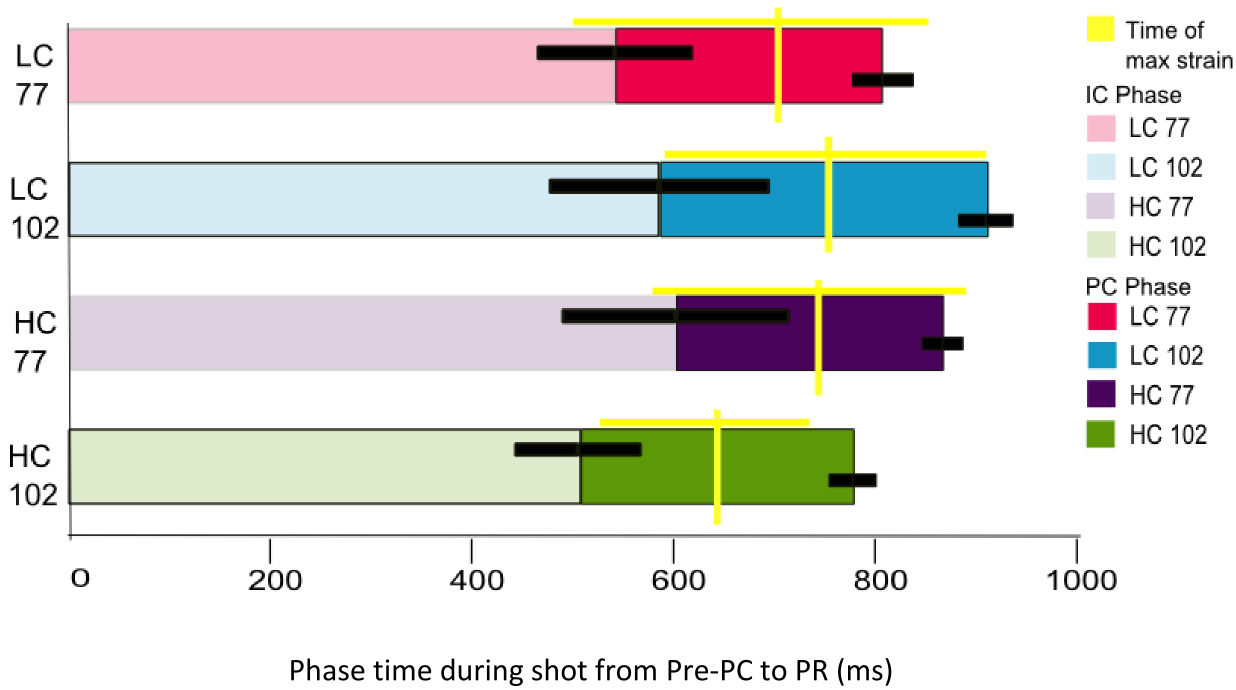

Figure 21: Pre-puck contact and puck contact phases by stick and calibre. Data are $\bar{x} \pm$ SEM for WS. No statistical significance was seen ($p \geq 0.05$). The yellow line denotes the approximate time to maximum strain for each stick using SG2 as a reference

Chapter 5: Discussion

5.0 General Discussion

As expected, player calibre significantly influenced resulting puck velocity for both SS and WS, such that HC players achieved were 4 to 5 m/s faster than LC. These results were consistent with Wu et al. (2003) study of elite and recreational level players. As well, puck velocity was not substantially affected by stick model (shaft stiffness, a.k.a flex). This finding, too, agrees with previous observations by Pearsall et al. (1999), Wu et al. (2003), and Worobets et al. (2006). Stick deformation was affected by player calibre. In general, again as anticipated, high calibre players deformed the sticks' shaft more (i.e. higher strain) than the LC players. Similar observations were noted by Wu et al. (2003), where HC players produced greater shaft bend angles than LC. Stick deformation was affected by stick model. As expected, the less stiff ranked stick (77 flex) bent more than the higher stiffness stick (102 flex). This is consistent with Castigliano's Theorem (Hodges, 2000) when taking into account the differences in modulus of elasticity for the different shaft stiffness.

In summary, the use of multiple strain gauge pairs along the shaft's length is a unique technique that can be used to assess the dynamic mechanic properties of hockey sticks. Furthermore, it clearly demonstrated the ability to distinguish between shot type (strains SS > WS), player calibre (strains HC > LC) and stick models (strain 77 > 102); hence, a useful analytical approach.

A rank order was seen in strain maxima, decreasing in magnitude proportional to the distance from SG2. To the author's knowledge, this is the first study to document variable flexion properties along a stick's shaft. SG2 consistently showed the greatest strain and presumably greatest bend (Hibbiler (2007). It was the gauge in closest proximity to the lower hand placement where the perpendicular force to the shaft's (beam's) long axis was applied (Figures 13 and 19). This hand location (± 100 mm) was observed consistently in both SS and WS irrespective of stick or player calibre.

Some instances of large variability of outcome measures were noted, this could be due to the wide variability of the shots used since a very large target (an entire empty hockey net) was used. Differences in how players may have learned the SS and WS technique were not accounted for.

Credit must be given to the seminal research of Doré and Roy (1973) where the application of strain gauges on stick shafts was first attempted. They noted that the amplitude of the strain curves was positively related to the overall puck velocity, but not force production. This trend was observed in this study when comparing maximum strains obtained by calibre with maximum puck velocities by calibre group. This observation confirms the importance of the shooter kinematics in relation to stick bend and puck velocity.

5.1 Slap shots

The kinematic movements of the trail arm's wrist and hand (i.e. the lower hand holding the stick) and stick were recorded in an attempt to identify technique differences between HC and LC. In general, no differences were observed except for elbow. HC shooter's average elbow flexion (39.2°) at PR was similar to that found in Goktepe et al. (2010), were as LC shooters tend to have greater elbow flexion (46.2°) the entire time the stick is in contact with the puck, from PC to PR. With regards to the stick's kinematics, LC players had a higher maximum blade pitch (i.e. 106.8°, blade face more towards the ice versus 100.4° for HC), confirming the observation by Lomond et al. (2007). As noted above, hand placement of the trailing arm during the SS was placed between SG2 and SG3, which coincided closely with the location of most strain within the stick (Figure 13). Hand location along the shaft was similar to that recorded by Wu et al. (2003). How these variables may affect puck velocity is not clearly evident, however, they could play a role in the strategy of the horizontal trajectory of the stick and puck. These could act together to create a coordination pattern to allow maximal horizontal force translated to the puck as well as minimize the vertical force dissipation lost when the stick hits the ice. Woo et al. (2004) noted there were kinematic differences based on group calibre, where the follow through coordination of the SS is different between calibres and the translational velocity of the blade of the stick is significantly higher in HC than LC (13.14 m/s vs 9.08 m/s).

Substantial differences in total shot durations were found such that HC executed the task 3 to 4 times faster than LC players (84.9 versus 349.3 ms). This pattern was consistent for both pre-puck contact and puck contact phases. To the author’s knowledge, this is the first instance where such a large player calibre effect has been recorded from the first instant of ice contact to PR, however Lomond and associates (2007) observed a similar trend in the timing of the Pre-PC phase, where the LC spent a significantly greater amount of time in this phase, than did the HC shooters (170 ms vs 140 ms). Although Villaseñor-Herrera et al (2006) did not observe the Pre-PC phase, the timing of the maximum peaks of strain were similar to the timing found in the present study. With regards to strain rates, given HC’s combined smaller shot duration and greater overall stick bending, both HC’s strain loading and decay rates were approximately 2 x greater than observed for LC players (Figures 16, 17). Furthermore, the timing of maximum strains occurred at different proportional phases during the shot. For example, for HC players strain maxima occurred to 38% of shot duration (Pre-PC to PR), while for LC players it occurred at 81%

(Figure 15). As a consequence of these factors above, the technique of the HC players augmented stick bend and bend rate as well as optimized the stick's elastic recoil (unbending) to occur during full puck contact, thus permitting greater energy transfer to the puck ergo greater puck velocity. In the case of the LC players, stick recoil was incomplete before the puck had already been released, thus losing stick elastic energy transfer to the puck. This latter observation is similar to that described by Villaseñor-Herrera (2004).

No significant differences were observed in time to maximum strains between stick flex 77 and 102 in this study. Pearsall and associates (1999) observed that the stiffness of the shaft affected the time to maximum strain, where the more stiff the shaft, the longer it took to reach the maximum peak when comparing the most flexible shaft (13 KN/m) taking 28 ms to the two most rigid shafts (17 KN/m and 19 KN/m) taking 25 ms and 24 ms respectively. The difference in results could be due to different measuring techniques of time to maximum strain.

The double peak phenomenon of the lower gauge maxima is present in both calibres and stick conditions to some extent (seen in figure 12). This unique wave form characteristic is observed in the strain gauges below the lower hand placement and informs us that at the locations below the hand the strain gauges are measuring a rapid change in the degree of deformation. The stick bends at these lower gauge locations, starts to return back to neutral position and then a second deformation is observed before PR. Technique of the shot is similar to that of a three-point-bending load, where the upper hand and ice surface act as constraints and the lower hand applies the load. After making contact with the ice surface, it makes contact with the puck (PC) and an additional load is applied (Bigford and Smith, 2009). This second load may help to explain the deformation wave pattern that is observed. Many additional factors could be contributing to the degree bend including the external forces acting upon the stick as well as the stick properties themselves including the stretch, shear, torsional and flexional properties of the stick (Hodges, 2000). Whether this is vibration or mechanical property of the stick or whether this characteristic is beneficial or destructive is unknown. It may be related to the overall shooter perception or subjective “feel” of the stick.

5.2 Wrist shots

Kinematic data of wrist flexion/extension at PR was consistent with that found by Magee (2009), confirming the wrist “flick” phenomenon (i.e. rapid wrist flexion) in the HC group when performing a WS. Although Magee’s study used accuracy as an outcome measure for shots at four random targets, similar HC/LC differences in wrist technique were present in the current study (no aiming task other than hitting the net). In addition, HC players used a wider base of support at PR than

LC. Similar findings were noted by Magee (2009) who speculated that this may enhance HC players' balance and/or weight transfer during the shot thereby improving puck trajectory accuracy and speed. Unlike Magee's study, differences in forearm pronation/supination movement were not shown between HC and LC, probably because lateral target location was not a factor in the current study.

The hand placement of the trailing arm is much higher up the shaft of the stick in the WS than in the SS performance (Figures 13, 19). Small differences in hand placement between the two calibres for both shots were not significant, hence the greater stick deformation shown by HC players had to be due to greater applied force to the stick shaft. As both HC and LC had similar grip strength and body mass measures, increased perpendicular force to the stick must be due to differences in loading technique yet to be determined. The timing of the PC phase was found to be comparable to that of Magee (2009). As well, no significant differences between sticks and calibre were seen in the timing of this shot, in part due to the substantial intersubject variability. The relative stick strain profile from SG1 to SG5 were similar to that observed during the slap shot, such that a rank order was observed in strain magnitudes roughly inversely proportional to the distances from the hand position (Figure19). Significant differences in strain at SG1, SG3 to SG5 were shown between both player calibre and between stick models. The latter significance of stick model (greater strains in flex 77 than 102) was not evident during slap shots. Hence the inherent flex properties of the stick are demonstrated during wrist shots.

In summary, the DSPs paint clear pictures of stick deformation from IC to PR. Changes occurred in the DSP depending on calibre and stick shaft stiffness, where HC obtained higher amplitudes with quicker strain and decay for both shots, and the 77 flex stick produced more strain than that of the 102 flex along the shaft for both shots. Kinematic differences by calibre were noted in both the SS and WS.

Chapter 6: Conclusions

Comparing the aforementioned hypotheses and the results obtained, a partial acceptance of expected outcomes was achieved. Maxima strain and strain rates were found to vary by calibre for SS and WS (accept H1); however, though influential during WS, these dependant measures were not affected significantly by stick model during SS (reject H1). There was an observed correspondence between lower hand placement and location of the gauge with the highest recorded strain. Time to peak strain was significantly higher in LC in SS (accept H2) but and not significant during WS (reject H2). Differences in calibre were noted for greater stick flexion in both SS and WS for HC, increased variability in the lower arm kinematics for HC, and a wider base of support for HC was observed in the WS condition (accept H3). H3 was rejected when comparing grip strength, contact time, time to peak strain, and relative lower hand placement.

A deeper understanding of how the DSP is affected under different conditions from IC to PR was achieved by this study. The strain gauge measurement system configuration and data acquisition provided appropriate temporal and spatial resolution allowing identification of dynamic bend characteristics of ice hockey sticks. The strain gauges provided a robust measurement system where no gauge failure occurred during testing. The relative strain responses at different gauge locations were valid as instrumentation and protocol were sufficient to identify differences and interactions between calibre and stick model. The kinematic analysis, through the use of Vicon MX®, was capable of capturing lower arm kinematic differences between calibres. The testing protocol was very efficient as each subject performed the protocol within 30 minutes.

The system and protocol used in the present study have been proven effective in research design to evaluate DSPs of sticks. Future studies could implement sticks with different “kick points” to further understand how the DSP and kinematics of the shooter are affected during hockey shots. Additional investigation into the bimodal maxima of the lower strain gauges during SS, perhaps by way or modal analyses, may be beneficial, as well as qualitative study, in order to unmask the this effect on the shooter's perception of the stick, as well as stick manipulation. Other strain gauge configurations, possibly implementing some to record torsion, may help identify reasons for the maximal strain and puck velocity differences between calibres. The development of a portable system to take on the ice may help to provide a more realistic testing environment. Future work should examine how perception may affect the performance outcomes (i.e. how the "feel" of the stick affects puck velocity or accuracy). From a manufacturing perspective, this system allows for the evaluation of the differences in additional flex profiles of the shaft not tested in this study. Eventually, this information may lead to player skill and training development.

References

Alpini, D., Hahn, A., & Riva, D. (2008) Static and dynamic postural control adaptations induced by playing ice hockey. *Sport science and health* 2:85-92

Baker, R. (2007) The history of gait analysis before the advent of modern computers. *Gait & posture* 26: 331-342.

Bahamonde R.E. & Knudson, D. (2003) Kinetics of the upper extremity in the open and square stance tennis forehand. *Journal of science and medicine in sport* 6(1): 88-101.

Bigford, R.L., Smith, L.V. (2009) Experimental characterization of ice hockey pucks and sticks. *Journal of ASTM international* 6(7)1:8

Blackwell, J.R., Kornatz, K.W. & Heath, E.M. (1999) Effect of grip span on maximal grip force and fatigue of flexor digitorum superficialis. *Applied ergonomics* 30:401-405.

Budynos, R.G, Norbett, J.K.(2006) *Shigley's Mechanical Engineering Design,* 8ed. McGraw-Hill Engineering, Columbus, OH

Button, C., MacLeod, M., Sanders, R., & Coleman, S. (2003). Examining movement variability in the basketball free throw action at different skill levels*. Research quarterly for exercise and sport* 74(3): 257–269.

Clarys, J.P. & Alewaeters, K. (2003)Science and sports: a brief history of muscle, motion and ad hoc organizations. *Journal of Sports Sciences* 21:669-677.

Delay, D., Nougier, V., Orliaguet, J.P., & Coello, Y. (1997). Movement control in golf putting. *Human movement science* 16:597-619.

Delisle, A., Gagnon, M., & Desjardins, P. (1998) Knee flexion and base of support in asymmetrical handling: effects on the worker's dynamic stability and the movements of the L5/S1 and knee joints. *Clinical biomechanics* 13:506-514

Doré , R., & Roy, B. (1973)Dynamometric analysis of different hockey shots. In: *Biomechanics,* vol 5B. *Proceedings of the Fourth International Congress of Biomechanics.* Baltimore: University Park Pess. 277-285.

Duplacey.A (1996) *The rules of hockey*. Toronto:Dan Diamond

Emmert, W. (1984). "The slap shot: Strength and contitioning program for hockey at Boston College." *National strength and conditioning association journal* **6**(2): 4-6,68,71,73.

Erdfelder, E., Faul, F., & Buchner, A. (1996). GPOWER: A general power analysis program. *Behaviour Research Methods, Instruments, & Computers 28*:1-11.

Goptke,A., Ozfidan, I., Karabork, H., & Korkusuz, F. (2010) Elbow but not knee joint kinematics can be assessed using photogrammetric methods during a non-stationary slap shot in ice hockey. *Scientific research and essays* 5(3):339-342

Hamill, J., & Knutzen, K.M. (2003) Biomechanical basis of human movement, 2 ed. Lippincot Willams & Wilkins, Baltimore, MD.

Hayes, D. (1964) A mechanical analysis of the hockey slap shot. *Journal of Canadian association of health, physical education, and recreation* 31(2):17

Hibbiler, R.C (2007) *Engineering Mechanics, Statis and dynamics*, 11 ed. Pearson, Prentice-Hall, Upper Saddle River, NJ.

Hockey Canada. (2007). About hockey Canada. Retrieved 2 November, 2008, from the hockey Canada website: http://www.hockeycanada.ca/index.cfm/ci_id/6698/la_id/1.htm .

Hodges, D.H. (2000) Nonlinear composite beam theory. *Progress in astronautics and aeronautics* Vol.213

Hoerner, E. F., Ed. (1989). The dynamic role played by the ice hockey stick. *Safety in ice hockey*. Philadelphia, American society for testing and materials.

Howell, D.C. 2007. Statistical methods for psychology, 6 ed. Thomson Wadsworth, Belmont, CA

Lafontaine, D. (2007) Three-dimensional kinematics of the knee and ankle joints for the three consecutive push-offs during ice hockey skating starts. *Sports Biomechanics 6* (3): 391-406.

Lehman, G.J. (2005) The influence of grip width and forearm pronation/supination on upper-body myoelectric activity during the flat bench press. *Journal of strength and conditioning research* 19(3):587-591.

Lomond, K. V., Turcotte, R.A. & Pearsall, D.J. (2007). Three-dimensional analysis of blade contact in an ice hockey slap shot, in relation to player skill. *Sports engineering* 10:87-100.

MacKenzie, S.J., & Sprigings, E.J. (2009) Understanding the role of shaft stiffness in the golf swing. *Sports engineering* 12:12-19.

Magee, P.M.., Dixon, P., Stidwell,T.J, Pearsall, D.J., Turcotte, R.A., & Covo, K.(2008) Portable strain measurement system for ice hockey sticks. *North American congress on biomechanics.*

Magee, P.M. (2009) *Whole-body predictors of wrist shot accuracy in ice hockey: A kinematic analysis by way of motion capture.* Unpublished master's thesis, McGill University, Montreal, QC, Canada.

Major, P., Ed. (1936). *Ice-hockey*. London, George Routledge & Sons, Ltd.

Marino, G. W.(1998). Biomechanical investigations of performance characteristics of various types of ice hockey sticks. In H.J. Riele & M.M. Vieten (eds) *International society of biomechanics in sport.* Konstanz, Germany

Mathiyakom, W. & McNitt-Gray, J.L. (2008) Regulation of angular impulse during fall recovery. *Journal of rehabilitation research and development* 45(8):1237-1248.

McLester, J., St.Pierre, P. (2008) Applied biomechanical concepts and connections. Thompson Wadsworth, Belmont, CA

Michaud-Paquette, Y., Pearsall, D.J., & Turcotte, R.A. (2008) Predictors of scoring accuracy: ice hockey wrist shot mechanics. *North American congress on biomechanics.*

Milburn, P. D. (1982) Summation of segmental in the golf swing. *Medicine and science in sports and exercise* 14:60–64

Minetti, A.E. (2004) Passive tools for enhancing muscle-driven motion and locomotion. *The Journal of experimental biology* 207:1265-1272

Montgomery, D.L., Nobes, K., Pearsall, D.J. & Turcotte, R.A. (2004) Task Analysis (hitting, shooting, passing and skating) of professional hockey players. *Safety in ice hockey: fourth volume, ASTM STP 1446*, D.J. Pearsall and A.B, Ashate, Eds., ASTM International, West Conshohocken, PA, 2004

Nazar, P. R. (1971). A comparison between the curved blade and straight blade hockey sticks on shooting velocity and accuracy in university varsity ice hockey players, University of Minnesota. *M.Sc.*:143.

Pan,W.T., Campbell, D.C., Richards, j.G., Bartolozzi, A.R. Ciccotti, M.G., and Snyder-Mackler, L. (1998) Effect of upper extremity strength training on puck speed in collegiate ice hockey players. In *1998 International symposium safety in ice hockey*

Pearsall, D.J., Montgomery, N., Rothsching,N., & Turcotte, R.A. (1999) The influence of stick stiffness on the performance of ice hockey slap shots. *Sports engineering* 2:3-11

Pearsall, D.J. & Turcotte, R.A. (2007) Design and materials in ice hockey. *Materials in sports equipment* Vol. 2. Aleksandar Subic. Woodhead Publishing Limited. Cambridge.

Pearsall, D. J., Turcotte, R.A. & Murphy, S.D., Ed. (2000). Biomechanics of Ice Hockey. *Exercise and sport science*. Philadelphia, Lippincott, Williams & Wilkins.

Roy, B., & Doré , R. (1973) Kinematics of the slap shot in ice hockey as executed by players of different age classifications. In:*Biomechanics* vol 5B. *Proceedings of the fourth international congress of biomechanics*. Baltimore: University Park Press, 286-290

Shimizu, T., Tsuchida,M., Kawai, K., Takahashi, K., Arakawa, K. & Satoh, M. (2009) An analysis of hte putter face control mechanism in golf putting. *Sports engineering* 12:21-30.

Stretch, R., Buys, R., duToit, E. & Viljoen, G. (1998) Kinematics and kinetics of the drive off the front food in cricket batting. *Journal of sports sciences* 16:711-720.

Sutherland, D.H. 2002. The evolution of clinical gait analysis: Part II kinematics. *Gait and posture* 16:159-179.

Villaseñor-Herrera, A.(2006) Recoil effect of the ice hockey stick during a slap shot. *Journal of applied biomechanics* 22(3):202-211

Woo, T., Loh, J., Turcotte, R., & Pearsall, D. (2004). The ice hockey slap shot, elite versus recreational. *International society of biomechanics in sport,* Ottawa.

Worobets, J.T., Fairbairn, J.C., & Stefanyshyn, D.J. (2006) *Sports engineering* 9:191-200

Wu, T-C., Pearsall, D., Hodges, A., Turcotte, R., & Lefebvre, R., (2003). The performance of the ice hockey slap and wrist shots: the effect of stick construction and player skill. *Sports engineering* 6(1):31-39

Vicon Motion Systems (1998) Plug-in gait product guide.

Vaughn, G. (1996) The puck starts here: the origin of Canada's great winter game: ice hockey. Four East Publications, Fredericton, NB.

Appendix I

Anatomy of an ice hockey stick

Appendix II Table of Abbreviations used in text

Abbreviation	Significance
SS	Slap shot
WS	Wrist shot
HC	High calibre
LC	Low calibre
DSP	Dynamic strain profile
Pre-PC	Time from ice contact to puck contact of the hockey stick blade
PC	Instant of blade and puck contact
PR	Instant of puck release from the blade
∆PC-PR	Change from puck contact to puck release
S	Stick marker
SG	Strain gauge

Appendix III

McGill

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Research Ethics Board II
Certificate of Ethical Acceptability of Research Involving Humans

REB File #: 86-0909

Project Title: Dynamic flex profile during a slap shot and wrist shot based on shooter calibre

Principal Investigator: Ashley Hannon **Department:** Kinesiology&Physical Education

Status: Master's student **Supervisor:** Prof. R. Turcotte

Co-investigator: Prof. David. Pearsall

Funding Agency/Title: N/A

This project was reviewed on Sept. 21, 2009 by

Expedited Review ✓
Full Review ___

Mark Baldwin, Ph.D.
Chair, REB II

Approval Period: Sept. 21, 2009 **to** Sept. 20, 2010

This project was reviewed and approved in accordance with the requirements of the McGill University Policy on the Ethical Conduct of Research Involving Human Subjects and with the Tri-Council Policy Statement: Ethical Conduct For Research Involving Humans.

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* All research involving human subjects requires review on an annual basis. A Request for Renewal form should be submitted 2-3 weeks before the above expiry date.
* When a project has been completed or terminated a Final Report form must be submitted.
* Should any modification or other unanticipated development occur before the next required review, the REB must be informed and any modification can't be initiated until approval is received.

McGill

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Ashley Hannon

INFORMATION AND CONSENT DOCUMENT

Investigator: Ashley Hannon, M.Sc. candidate
René A. Turcotte, PhD
David J. Pearsall, PhD
Biomechanics Laboratory, Department of Kinesiology and Physical Education, McGill University

Statement of Invitation

You are invited to participate in a research project conducted by the above named investigators. Data collection for this research project will be performed in the Biomechanics Laboratory of the Department of Kinesiology and Physical Education, McGill University, located at 475 Pine Ave West, Montréal, Québec H2W 1S4. You are asked to come to one experimental session that will last up to 1 hour. I greatly appreciate your interest in my work.

Purpose of the Study

The purpose of this study is to investigate kinematic and kinetic data related to the slap and wrist shots in ice hockey along with the associated strain measurements captured in the hockey stick shaft. The overall goal of this study is to gain knowledge about the response of the hockey stick during a slap shot and wrist shot.

Your participation in this study involves:

1. Providing informed consent prior to the experimental session,
2. Providing data concerning your physical attributes and hockey experience (e.g., height, gender, age, and different anthropometric segment measurements),
3. Performing a grip strength test and maximum bench press test,
4. Carrying out several slap shot and wrist shot trials wearing ice hockey skates and gloves with reflective markers on an artificial ice surface while manipulating a hockey stick and puck.

Risks and Discomforts

It is anticipated that you will encounter no significant discomfort during these experiments. There are no risks associated with these experiments. An experimenter will stand close to you at all times during the sessions.

Benefits

There are no personal benefits to be derived from participating in this study. Documenting the kinematic and kinetic differences in stick handling mechanics between skill levels will optimistically help increase the understanding, coaching, and performance of stick handling in the sport of ice hockey.

Confidentiality
All the personal information collected during the study you concerning will be encoded in order to keep their confidentiality. These records will be maintained at the Biomechanics Laboratory by Dr. René A. Turcotte for 5 years after the end of the project, and will be destroyed upon the expiration of this time frame. Only members of the research team will be able to access them. In case of presentation or publication of the results from this study nothing will enable your identification.

Inquiries Concerning this Study
If you require information concerning the study (experimental procedures or other details), please do not hesitate to contact *Ashley Hannon*, at the numbers or addresses listed at the top of this document.

Responsibility clause
In accepting to participate in this study, you will not relinquish any of your rights and you will not liberate the researchers or their sponsors or the institutions involved from any of their legal or professional obligations.

Consent
Please be advised that your participation in this research undertaking is strictly on a voluntary basis, and you may withdraw at any time.

A copy of this form will be given to you before the end of the experimental session.

APPROVAL SEP 2 1 [illegible]

CONSENT

I, ____, AGREE TO VOLUNTARILY PARTICIPATE IN THE STUDY DESCRIBED ABOVE ABOUT THE COORDNIATION OF POSTURE AND VOLUNTARY MOVEMENT.

I HAVE RECEIVED AND READ A DETAILED DESCRIPTION OF THE EXPERIMENTAL PROTOCOL. I AM FULLY SATISFIED WITH THE EXPLANATIONS THAT WERE GIVEN TO ME REGARDING THE NATURE OF THIS RESEARCH PROJECT, INCLUDING THE POTENTIAL RISKS AND DISCOMFORTS RELATED TO MY PARTICIPATION IN THIS STUDY.

I am aware that I have the right to withdraw my consent and discontinue my participation at any time without any prejudices.

Signatures

SUBJECT

__________________________________ (signature)

__________________________________ (print name)

RESEARCHER

__________________________________ (signature)

__________________________________ (print name)

Date: ________________________

APPROVED SEP 2 1 20[illegible]

Appendix IV

	Condition	M	SD	n	SE	F	*p*
			Slap Shot				
			PC				
			Calibre				
Elbow flexion/extension at PC (°)	LC	51.0	7.1	16	1.8	10.363	0.003
	HC	40.5	11.1	18	2.6		
Grip width at PC (mm)	LC	774.9	77.1	16	19.3	0.017	0.898
	HC	771.2	83.6	18	19.7		
Lower hand placement at PC (mm)	LC	681.6	64.0	16	16.0	0.052	0.821
	HC	674.9	98.7	18	23.3		
Stance width at PC (mm)	LC	857.5	167.2	16	41.8	0.028	0.869
	HC	850.3	82.6	18	19.5		
Wrist flexion/extension at PC (°)	LC	-9.7	21.0	16	5.3	1.103	0.302
	HC	-15.9	12.9	18	3.0		
Radial/ulnar deviation at PC (°)	LC	127.8	36.8	16	9.2	0.035	0.852
	HC	130.0	27.3	18	6.4		
Forearm pronation/supination at PC (°)	LC	115.4	32.3	16	8.1	0.013	0.912
	HC	113.9	39.9	18	9.4		
Blade pitch at PC (°)	LC	85.6	18.7	16	4.7	0.037	0.848
	HC	84.3	17.5	18	4.1		
Blade roll at PC (°)	LC	92.8	25.7	16	6.4	0.302	0.587
	HC	97.4	21.7	18	5.1		
Stick bend at PC (°)	LC	2.9	3.4	16	0.9	1.086	0.306
	HC	3.9	1.7	18	0.4		
Blade yaw at PC (°)	LC	70.4	5.4	16	1.3	2.759	0.107
	HC	67.6	4.3	18	1.0		
SG1 at PC (με)	LC	342.7	256.3	16	64.1	3.145	0.086
	HC	650.3	635.6	18	149.8		
SG2 at PC (με)	LC	646.1	578.6	16	144.7	1.611	0.214
	HC	1018.0	995.0	18	234.5		
SG3 at PC (με)	LC	332.1	223.7	16	55.9	6.434	0.017
	HC	838.1	744.9	18	175.6		
SG4 at PC (με)	LC	214.0	134.9	16	33.7	7.702	0.009
	HC	642.2	583.6	18	137.6		
SG5 at PC (με)	LC	145.0	86.8	16	21.7	8.394	0.007
	HC	491.6	455.9	18	107.5		
			Stick				
Elbow flexion/extension at PC (°)	77	45.2	10.8	17	2.6	0.045	0.834
	102	45.7	11.0	17	2.7		
Grip width at PC (mm)	77	770.4	71.9	17	17.4	0.020	0.889
	102	775.4	88.4	17	21.4		

Lower hand placement at PC (mm)	77		683.6	63.4	17	15.4	0.104	0.749
	102		672.5	100.7	17	24.4		
Stance width at PC (mm)	77		886.3	145.1	17	35.2	2.487	0.125
	102		821.2	100.9	17	24.5		
Wrist flexion/extension at PC (°)	77		-12.2	11.9	17	2.9	0.132	0.718
	102		-13.9	21.7	17	5.3		
Radial/ulnar deviation at PC (°)	77		129.9	30.5	17	7.4	0.021	0.885
	102		128.1	33.7	17	8.2		
Forearm pronation/supination at PC (°)	77		112.0	35.7	17	8.6	0.136	0.715
	102		117.2	37.2	17	9.0		
Blade pitch at PC (°)	77		85.6	15.5	17	3.8	0.043	0.836
	102		84.2	20.3	17	4.9		
Blade roll at PC (°)	77		95.4	20.7	17	5.0	0.005	0.945
	102		95.0	26.5	17	6.4		
Stick bend at PC (°)	77		3.5	1.7	17	0.4	0.001	0.981
	102		3.4	3.4	17	0.8		
Blade yaw at PC (°)	77		67.8	5.1	17	1.2	1.602	0.215
	102		69.9	4.8	17	1.2		
SG1 at PC (με)	77		583.9	601.8	17	146.0	0.806	0.376
	102		427.2	407.1	17	98.7		
SG2 at PC (με)	77		821.5	784.3	17	190.2	0.024	0.877
	102		864.5	907.2	17	220.0		
SG3 at PC (με)	77		645.7	688.9	17	167.1	0.213	0.648
	102		554.3	541.3	17	131.3		
SG4 at PC (με)	77		446.2	506.5	17	122.9	0.007	0.932
	102		435.2	468.4	17	113.6		
SG5 at PC (με)	77		331.7	392.7	17	95.2	0.005	0.944
	102		325.2	370.5	17	89.9		
Calibre*Stick								
Elbow flexion/extension at PC (°)	LC	77	48.5	4.8	8	1.7	1.715	0.200
		102	53.5	8.4	8	3.0		
	HC	77	42.3	13.9	9	4.6		
		102	38.7	7.9	9	2.6		
Grip width at PC (mm)	LC	77	781.6	85.9	8	30.4	0.375	0.545
		102	768.2	72.4	8	25.6		
	HC	77	760.5	60.5	9	20.2		
		102	781.9	104.6	9	34.9		
Lower hand placement at PC (mm)	LC	77	673.0	71.2	8	25.2	0.818	0.373
		102	690.2	59.6	8	21.1		
	HC	77	692.9	58.4	9	19.5		
		102	656.8	128.7	9	42.9		
Stance width at PC (mm)	LC	77	918.2	195.4	8	69.1	1.508	0.229
		102	796.9	115.3	8	40.8		
	HC	77	857.9	82.1	9	27.4		

		102	842.8	87.4	9	29.1		
Wrist flexion/extension at PC (°)	LC	77	-4.7	8.2	8	2.9	1.727	0.199
		102	-14.7	28.7	8	10.1		
	HC	77	-18.7	11.0	9	3.7		
		102	-13.1	14.7	9	4.9		
Radial/ulnar deviation at PC (°)	LC	77	127.1	39.4	8	13.9	0.074	0.788
		102	128.6	36.6	8	12.9		
	HC	77	132.4	22.0	9	7.3		
		102	127.6	33.1	9	11.0		
Forearm pronation/supination at PC (°)	LC	77	117.0	29.6	8	10.4	0.390	0.537
		102	113.7	36.8	8	13.0		
	HC	77	107.6	41.6	9	13.9		
		102	120.3	39.5	9	13.2		
Blade pitch at PC (°)	LC	77	85.6	19.9	8	7.0	0.035	0.853
		102	85.5	18.8	8	6.6		
	HC	77	85.6	11.7	9	3.9		
		102	83.1	22.6	9	7.5		
Blade roll at PC (°)	LC	77	95.0	27.2	8	9.6	0.222	0.641
		102	90.5	25.7	8	9.1		
	HC	77	95.7	14.5	9	4.8		
		102	99.0	28.0	9	9.3		
Stick bend at PC (°)	LC	77	2.2	0.7	8	0.2	2.636	0.115
		102	3.7	4.9	8	1.7		
	HC	77	4.6	1.5	9	0.5		
		102	3.2	1.6	9	0.5		
Blade yaw at PC (°)	LC	77	69.4	5.3	8	1.9	0.009	0.925
		102	71.3	5.6	8	2.0		
	HC	77	66.4	4.8	9	1.6		
		102	68.7	3.7	9	1.2		
SG1 at PC (με)	LC	77	412.4	332.6	8	117.6	0.009	0.926
		102	273.0	138.0	8	48.8		
	HC	77	736.3	756.3	9	252.1		
		102	564.3	519.5	9	173.2		
SG2 at PC (με)	LC	77	599.9	482.1	8	170.5	0.026	0.874
		102	692.4	692.9	8	245.0		
	HC	77	1018.6	966.5	9	322.2		
		102	1017.4	1081.6	9	360.5		
SG3 at PC (με)	LC	77	384.0	300.6	8	106.3	0.003	0.954
		102	280.3	103.7	8	36.7		
	HC	77	878.4	860.7	9	286.9		
		102	797.9	659.4	9	219.8		
SG4 at PC (με)	LC	77	239.6	183.0	8	64.7	0.060	0.807
		102	188.4	63.1	8	22.3		
	HC	77	629.8	635.0	9	211.7		

		102	654.5	565.9	9	188.6		
SG5 at PC (με)	LC	77	166.1	114.3	8	40.4	0.080	0.779
		102	123.9	45.4	8	16.1		
	HC	77	478.9	495.2	9	165.1		
		102	504.3	442.9	9	147.6		
		PR						
		Calibre						
Elbow flexion/extension at PR (°)	LC		46.2	6.3	16	1.6	6.561	0.016
	HC		39.2	8.7	18	2.0		
Grip width at PR (mm)	LC		790.5	72.4	16	18.1	0.074	0.787
	HC		784.7	47.6	18	11.2		
Lower hand placement at PR (mm)	LC		667.8	60.4	16	15.1	0.815	0.374
	HC		685.6	51.6	18	12.2		
Stance width at PR (mm)	LC		852.8	103.2	16	25.8	0.772	0.387
	HC		882.1	85.2	18	20.1		
Wrist flexion/extension at PR (°)	LC		-9.9	9.6	16	2.4	2.140	0.154
	HC		-13.8	5.8	18	1.4		
Radial/ulnar deviation at PR (°)	LC		127.3	36.0	16	9.0	0.094	0.761
	HC		130.5	21.2	18	5.0		
Forearm pronation/supination at PR(°)	LC		116.6	34.9	16	8.7	0.003	0.957
	HC		115.8	46.3	18	10.9		
Blade pitch at PR (°)	LC		95.5	12.6	16	3.1	1.054	0.313
	HC		91.5	9.7	18	2.3		
Blade roll at PR (°)	LC		83.2	17.7	16	4.4	0.990	0.328
	HC		88.3	11.0	18	2.6		
Stick bend at PR (°)	LC		2.9	2.5	16	0.6	0.037	0.849
	HC		2.7	2.1	18	0.5		
Blade yaw at PR (°)	LC		64.1	6.3	16	1.6	0.902	0.350
	HC		62.5	2.3	18	0.5		
SG1 at PR (με)	LC		161.4	698.1	16	174.5	1.863	0.182
	HC		-136.7	569.2	18	134.2		
SG2 at PR (με)	LC		530.8	1504.3	16	376.1	3.437	0.074
	HC		-226.3	727.1	18	171.4		
SG3 at PR (με)	LC		198.0	735.3	16	183.8	2.127	0.155
	HC		-129.8	557.2	18	131.3		
SG4 at PR (με)	LC		147.0	477.5	16	119.4	1.623	0.213
	HC		-38.7	357.4	18	84.2		
SG5 at PR (με)	LC		87.5	300.7	16	75.2	0.346	0.561
	HC		32.3	236.6	18	55.8		
		Stick						
Elbow flexion/extension at PR (°)	77		42.1	8.4	17	2.0	0.107	0.746
	102		42.9	8.5	17	2.1		
Grip width at PR (mm)	77		788.5	64.0	17	15.5	0.014	0.906
	102		786.4	56.9	17	13.8		

Lower hand placement at PR (mm)	77		679.1	61.6	17	15.0	0.022	0.883
	102		675.4	51.1	17	12.4		
Stance width at PR (mm)	77		868.8	84.6	17	20.5	0.000	0.986
	102		867.9	104.8	17	25.4		
Wrist flexion/extension at PR (°)	77		-14.1	7.8	17	1.9	2.429	0.130
	102		-9.9	7.7	17	1.9		
Radial/ulnar deviation at PR (°)	77		129.9	25.8	17	6.3	0.027	0.871
	102		128.0	32.1	17	7.8		
Forearm pronation/supination at PR(°)	77		113.6	41.6	17	10.1	0.132	0.719
	102		118.8	40.9	17	9.9		
Blade pitch at PR (°)	77		93.8	11.4	17	2.8	0.054	0.819
	102		93.0	11.2	17	2.7		
Blade roll at PR (°)	77		85.0	15.2	17	3.7	0.140	0.711
	102		86.8	14.3	17	3.5		
Stick bend at PR (°)	77		2.9	1.9	17	0.5	0.058	0.811
	102		2.7	2.6	17	0.6		
Blade yaw at PR (°)	77		63.5	5.0	17	1.2	0.122	0.729
	102		62.9	4.4	17	1.1		
SG1 at PR (με)	77		137.5	742.6	17	180.1	1.570	0.220
	102		-130.4	508.6	17	123.4		
SG2 at PR (με)	77		249.6	1200.3	17	291.1	0.330	0.570
	102		10.4	1231.1	17	298.6		
SG3 at PR (με)	77		139.6	747.7	17	181.3	1.111	0.300
	102		-90.7	553.7	17	134.3		
SG4 at PR (με)	77		121.2	465.0	17	112.8	1.020	0.321
	102		-23.8	374.6	17	90.8		
SG5 at PR (με)	77		101.0	286.7	17	69.5	0.790	0.381
	102		15.6	244.5	17	59.3		
Calibre*Stick								
Elbow flexion/extension at PR (°)	LC	77	45.6	5.7	8	2.0	0.014	0.906
		102	46.8	7.2	8	2.6		
	HC	77	38.9	9.4	9	3.1		
		102	39.5	8.4	9	2.8		
Grip width at PR (mm)	LC	77	796.0	81.1	8	28.7	0.158	0.694
		102	785.0	67.7	8	24.0		
	HC	77	781.7	48.2	9	16.1		
		102	787.7	49.6	9	16.5		
Lower hand placement at PR (mm)	LC	77	663.1	73.8	8	26.1	0.396	0.534
		102	672.6	48.3	8	17.1		
	HC	77	693.3	48.6	9	16.2		
		102	677.9	56.2	9	18.7		
Stance width at PR (mm)	LC	77	850.7	80.5	8	28.5	0.021	0.885
		102	855.0	127.7	8	45.2		
	HC	77	884.9	89.6	9	29.9		

		102	879.4	85.8	9	28.6		
Wrist flexion/extension at PR (°)	LC	77	-11.4	9.7	8	3.4	0.166	0.687
		102	-8.4	9.9	8	3.5		
	HC	77	-16.4	5.1	9	1.7		
		102	-11.2	5.5	9	1.8		
Radial/ulnar deviation at PR (°)	LC	77	126.7	33.2	8	11.7	0.084	0.775
		102	127.9	41.0	8	14.5		
	HC	77	132.8	18.8	9	6.3		
		102	128.1	24.2	9	8.1		
Forearm pronation/supination at PR(°)	LC	77	113.0	37.3	8	13.2	0.017	0.897
		102	120.3	34.4	8	12.2		
	HC	77	114.1	47.3	9	15.8		
		102	117.5	48.0	9	16.0		
Blade pitch at PR (°)	LC	77	96.9	13.5	8	4.8	0.214	0.647
		102	94.2	12.3	8	4.4		
	HC	77	91.0	9.0	9	3.0		
		102	92.0	10.8	9	3.6		
Blade roll at PR (°)	LC	77	80.8	19.0	8	6.7	0.300	0.588
		102	85.5	17.2	8	6.1		
	HC	77	88.7	10.6	9	3.5		
		102	87.8	12.1	9	4.0		
Stick bend at PR (°)	LC	77	2.5	2.5	8	0.9	1.160	0.290
		102	3.2	2.6	8	0.9		
	HC	77	3.3	1.4	9	0.5		
		102	2.2	2.6	9	0.9		
Blade yaw at PR (°)	LC	77	64.3	7.3	8	2.6	0.009	0.927
		102	63.8	5.7	8	2.0		
	HC	77	62.9	1.4	9	0.5		
		102	62.1	3.0	9	1.0		
SG1 at PR (με)	LC	77	347.7	932.2	8	329.6	0.205	0.654
		102	-24.9	309.8	8	109.5		
	HC	77	-49.3	508.8	9	169.6		
		102	-224.1	642.2	9	214.1		
SG2 at PR (με)	LC	77	607.6	1614.2	8	570.7	0.039	0.844
		102	454.0	1493.4	8	528.0		
	HC	77	-68.6	599.7	9	199.9		
		102	-384.0	841.4	9	280.5		
SG3 at PR (με)	LC	77	372.2	974.7	8	344.6	0.247	0.623
		102	23.7	373.2	8	132.0		
	HC	77	-67.2	429.6	9	143.2		
		102	-192.4	683.0	9	227.7		
SG4 at PR (με)	LC	77	239.6	617.5	8	218.3	0.068	0.796
		102	54.3	296.2	8	104.7		
	HC	77	15.9	269.0	9	89.7		
		102	-93.4	438.5	9	146.2		

SG5 at PR (με)	LC	77	111.6	367.7	8	130.0	0.141	0.710
		102	63.4	239.2	8	84.6		
	HC	77	91.6	214.3	9	71.4		
		102	-26.9	255.2	9	85.1		
Δ PC-PR								
Calibre								
Elbow flexion/extension Δ PC-PR (°)	LC		-4.4	9.8	16	2.5	1.019	0.321
	HC		-1.4	7.3	18	1.7		
Grip width Δ PC-PR (mm)	LC		13.8	56.4	16	14.1	0.002	0.968
	HC		13.0	52.0	18	12.3		
Lower hand placement Δ PC-PR (mm)	LC		-13.8	44.7	16	11.2	1.352	0.254
	HC		10.7	70.8	18	16.7		
Stance width Δ PC-PR (mm)	LC		-7.7	163.7	16	40.9	1.039	0.316
	HC		30.6	21.5	18	5.1		
Wrist flexion/extension Δ PC-PR (°)	LC		-2.5	11.6	16	2.9	1.238	0.275
	HC		3.0	16.5	18	3.9		
Radial/ulnar deviation Δ PC-PR (°)	LC		-0.5	15.0	16	3.7	0.396	0.534
	HC		2.9	15.5	18	3.7		
Forearm pronation/supination Δ PC-PR (°)	LC		1.0	23.4	16	5.9	0.000	0.990
	HC		0.9	26.2	18	6.2		
Blade pitch Δ PC-PR (°)	LC		10.8	26.2	16	6.6	0.182	0.673
	HC		6.9	25.3	18	6.0		
Blade roll Δ PC-PR (°)	LC		-10.5	35.6	16	8.9	0.021	0.885
	HC		-8.8	30.6	18	7.2		
Stick bend Δ PC-PR (°)	LC		0.6	2.5	16	0.6	3.567	0.069
	HC		-1.1	2.9	18	0.7		
Blade yaw Δ PC-PR (°)	LC		-5.8	10.8	16	2.7	0.057	0.813
	HC		-5.1	4.1	18	1.0		
SG1 Δ PC-PR (με)	LC		-181.3	713.1	16	178.3	5.172	0.030
	HC		-787.0	790.2	18	186.3		
SG2 Δ PC-PR (με)	LC		-751.5	3259.3	16	814.8	0.348	0.560
	HC		-1244.3	1279.1	18	301.5		
SG3 Δ PC-PR (με)	LC		-134.2	738.2	16	184.5	7.269	0.011
	HC		-967.9	981.6	18	231.4		
SG4 Δ PC-PR (με)	LC		-67.0	477.4	16	119.4	7.958	0.008
	HC		-680.9	718.1	18	169.3		
SG5 Δ PC-PR (με)	LC		-57.5	311.5	16	77.9	6.820	0.014
	HC		-459.3	523.1	18	123.3		
Stick								
Elbow flexion/extension Δ PC-PR (°)	77		-3.1	8.6	17	2.1	0.017	0.899
	102		-2.5	8.8	17	2.1		
Grip width Δ PC-PR (mm)	77		13.2	51.4	17	12.5	0.006	0.938

	102		13.6	56.7	17	13.8		
Lower hand placement Δ PC-PR (mm)	77		-4.5	31.3	17	7.6	0.097	0.757
	102		2.9	80.7	17	19.6		
Stance width Δ PC-PR (mm)	77		-16.1	151.3	17	36.7	2.571	0.119
	102		41.2	41.7	17	10.1		
Wrist flexion/extension Δ PC-PR (°)	77		-0.9	15.4	17	3.7	0.334	0.568
	102		1.6	13.8	17	3.4		
Radial/ulnar deviation Δ PC-PR (°)	77		0.7	12.7	17	3.1	0.060	0.808
	102		1.9	17.6	17	4.3		
Forearm pronation/supination Δ PC-PR (°)	77		2.7	20.5	17	5.0	0.109	0.743
	102		-0.7	28.5	17	6.9		
Blade pitch Δ PC-PR (°)	77		6.9	23.9	17	5.8	0.166	0.687
	102		10.6	27.5	17	6.7		
Blade roll Δ PC-PR (°)	77		-8.9	31.8	17	7.7	0.009	0.927
	102		-10.3	34.2	17	8.3		
Stick bend Δ PC-PR (°)	77		-0.8	2.3	17	0.6	1.017	0.321
	102		0.1	3.2	17	0.8		
Blade yaw Δ PC-PR (°)	77		-4.7	8.6	17	2.1	0.273	0.605
	102		-6.2	7.2	17	1.7		
SG1 Δ PC-PR (με)	77		-446.4	912.4	17	221.3	0.196	0.661
	102		-557.6	703.9	17	170.7		
SG2 Δ PC-PR (με)	77		-571.9	1422.8	17	345.1	1.202	0.282
	102		-1452.8	3064.2	17	743.2		
SG3 Δ PC-PR (με)	77		-506.1	1083.8	17	262.9	0.219	0.643
	102		-645.0	847.2	17	205.5		
SG4 Δ PC-PR (με)	77		-325.0	741.6	17	179.9	0.379	0.543
	102		-459.0	633.8	17	153.7		
SG5 Δ PC-PR (με)	77		-230.7	516.4	17	125.2	0.237	0.630
	102		-309.7	444.1	17	107.7		
Calibre*Stick								
Elbow flexion/extension Δ PC-PR (°)	LC	77	-2.7	8.6	8	3.0	1.578	0.219
		102	-6.1	11.3	8	4.0		
	HC	77	-3.5	9.1	9	3.0		
		102	0.6	4.3	9	1.4		
Grip width Δ PC-PR (mm)	LC	77	3.7	70.7	8	25.0	0.991	0.327
		102	23.9	39.8	8	14.1		
	HC	77	21.7	27.2	9	9.1		
		102	4.4	69.6	9	23.2		
Lower hand placement Δ PC-PR (mm)	LC	77	-9.9	39.0	8	13.8	0.455	0.505
		102	-17.6	52.2	8	18.5		
	HC	77	0.3	23.9	9	8.0		
		102	21.1	99.2	9	33.1		
Stance width Δ PC-PR (mm)	LC	77	-63.6	216.9	8	76.7	1.865	0.182

		102	48.1	57.0	8	20.1		
	HC	77	26.1	19.5	9	6.5		
		102	35.1	23.6	9	7.9		
Wrist flexion/extension Δ PC-PR (°)	LC	77	-7.1	8.9	8	3.1	1.648	0.209
		102	2.1	12.8	8	4.5		
	HC	77	4.7	18.1	9	6.0		
		102	1.2	15.5	9	5.2		
Radial/ulnar deviation Δ PC-PR (°)	LC	77	-2.2	13.7	8	4.8	0.145	0.707
		102	1.2	16.9	8	6.0		
	HC	77	3.3	11.9	9	4.0		
		102	2.5	19.2	9	6.4		
Forearm pronation/supination Δ PC-PR (°)	LC	77	-2.2	21.2	8	7.5	1.172	0.288
		102	4.3	26.5	8	9.4		
	HC	77	7.0	20.0	9	6.7		
		102	-5.2	31.1	9	10.4		
Blade pitch Δ PC-PR (°)	LC	77	9.5	30.3	8	10.7	0.016	0.901
		102	12.1	23.5	8	8.3		
	HC	77	4.5	18.1	9	6.0		
		102	9.4	32.0	9	10.7		
Blade roll Δ PC-PR (°)	LC	77	-12.5	42.1	8	14.9	0.191	0.665
		102	-8.5	30.6	8	10.8		
	HC	77	-5.7	21.4	9	7.1		
		102	-11.9	38.9	9	13.0		
Stick bend Δ PC-PR (°)	LC	77	-0.1	2.0	8	0.7	0.406	0.529
		102	1.4	2.8	8	1.0		
	HC	77	-1.3	2.6	9	0.9		
		102	-1.0	3.3	9	1.1		
Blade yaw Δ PC-PR (°)	LC	77	-5.7	12.0	8	4.2	0.207	0.652
		102	-5.9	10.2	8	3.6		
	HC	77	-3.8	4.4	9	1.5		
		102	-6.5	3.5	9	1.2		
SG1 Δ PC-PR (με)	LC	77	-64.7	1000.6	8	353.8	0.187	0.668
		102	-298.0	239.5	8	84.7		
	HC	77	-785.6	716.8	9	238.9		
		102	-788.4	901.8	9	300.6		
SG2 Δ PC-PR (με)	LC	77	7.8	1643.5	8	581.1	0.519	0.477
		102	-1510.7	4329.5	8	1530.7		
	HC	77	-1087.2	1025.0	9	341.7		
		102	-1401.4	1539.6	9	513.2		
SG3 Δ PC-PR (με)	LC	77	-11.8	1019.8	8	360.5	0.105	0.749
		102	-256.6	305.8	8	108.1		
	HC	77	-945.6	988.8	9	329.6		
		102	-990.3	1033.7	9	344.6		

SG4 Δ PC-PR (με)	LC	77	0.0	643.8	8	227.6	0.000	1.000
		102	-134.0	252.4	8	89.2		
	HC	77	-613.9	733.3	9	244.4		
		102	-747.9	740.4	9	246.8		
SG5 Δ PC-PR (με)	LC	77	-54.5	403.5	8	142.7	0.201	0.657
		102	-60.4	212.3	8	75.1		
	HC	77	-387.3	576.4	9	192.1		
		102	-531.2	487.5	9	162.5		
		Maxes						
		Calibre						
Elbow flexion/extension max (°)	LC		59.8	10.3	16	2.6	0.459	0.503
	HC		55.8	20.8	18	4.9		
Grip width max (mm)	LC		838.3	125.0	16	31.3	0.983	0.329
	HC		804.2	74.0	18	17.4		
Lower hand placement max (mm)	LC		718.4	75.9	16	19.0	0.076	0.784
	HC		712.2	53.7	18	12.7		
Stance width max (°)	LC		1744.9	3457.9	16	864.5	1.102	0.302
	HC		893.4	87.5	18	20.6		
Wrist flexion/extension max (°)	LC		1.7	8.8	16	2.2	1.010	0.323
	HC		-1.4	8.5	18	2.0		
Radial/ulnar deviation max (°)	LC		145.5	31.0	16	7.7	0.120	0.731
	HC		149.3	30.0	18	7.1		
Forearm pronation/supination max (°)	LC		141.4	23.6	16	5.9	0.025	0.875
	HC		139.6	39.4	18	9.3		
Blade pitch max (°)	LC		106.8	9.1	16	2.3	5.450	0.026
	HC		100.4	6.6	18	1.6		
Blade roll max (°)	LC		114.5	14.9	16	3.7	0.600	0.445
	HC		122.2	35.9	18	8.5		
Stick bend max (°)	LC		13.2	18.9	16	4.7	0.134	0.717
	HC		15.2	11.2	18	2.6		
Blade yaw max (°)	LC		81.1	11.4	16	2.9	0.168	0.685
	HC		79.5	11.6	18	2.7		
SG1 max (με)	LC		2773.9	878.8	16	219.7	10.509	0.003
	HC		3645.8	775.9	18	182.9		
SG2 max (με)	LC		3686.2	1432.3	16	358.1	7.257	0.011
	HC		4900.7	1171.3	18	276.1		
SG3 max (με)	LC		2596.6	761.2	16	190.3	18.852	0.000
	HC		3737.6	832.3	18	196.2		
SG4 max (με)	LC		1903.1	501.3	16	125.3	21.094	0.000
	HC		2713.0	573.0	18	135.1		
SG5 max (με)	LC		1589.9	731.5	16	182.9	4.153	0.050
	HC		1961.2	400.1	18	94.3		
Max Puck Velocity (m/s)	LC		22.4	6.6	16	1.6	6.126	0.019
	HC		27.2	4.2	18	1.0		

		Stick						
Elbow flexion/extension max (°)	77		56.6	15.4	17	3.7	0.156	0.696
	102		58.9	18.2	17	4.4		
Grip width max (mm)	77		835.8	121.6	17	29.5	0.968	0.333
	102		804.8	76.2	17	18.5		
Lower hand placement max (mm)	77		718.7	65.7	17	15.9	0.058	0.812
	102		711.6	64.3	17	15.6		
Stance width max (°)	77		1707.3	3350.6	17	812.6	1.172	0.288
	102		880.9	112.5	17	27.3		
Wrist flexion/extension max (°)	77		-0.8	9.0	17	2.2	0.334	0.568
	102		0.9	8.6	17	2.1		
Radial/ulnar deviation max (°)	77		147.0	30.4	17	7.4	0.012	0.914
	102		148.1	30.6	17	7.4		
Forearm pronation/supination max (°)	77		135.8	33.6	17	8.2	0.624	0.436
	102		145.1	31.6	17	7.7		
Blade pitch max (°)	77		103.0	8.7	17	2.1	0.052	0.822
	102		103.8	8.3	17	2.0		
Blade roll max (°)	77		118.3	25.9	17	6.3	0.002	0.967
	102		118.8	30.6	17	7.4		
Stick bend max (°)	77		13.9	16.9	17	4.1	0.020	0.889
	102		14.6	13.6	17	3.3		
Blade yaw max (°)	77		80.6	13.0	17	3.2	0.017	0.898
	102		79.9	9.9	17	2.4		
SG1 max (με)	77		3508.5	944.5	17	229.1	3.837	0.059
	102		2962.5	845.9	17	205.2		
SG2 max (με)	77		4597.1	1217.4	17	295.3	1.423	0.242
	102		4061.2	1589.8	17	385.6		
SG3 max (με)	77		3463.4	1045.7	17	253.6	3.769	0.062
	102		2937.9	853.4	17	207.0		
SG4 max (με)	77		2523.9	726.8	17	176.3	4.523	0.042
	102		2139.9	570.3	17	138.3		
SG5 max (με)	77		2047.2	706.7	17	171.4	8.169	0.008
	102		1525.7	317.4	17	77.0		
Max Puck Velocity (m/s)	77		24.7	6.1	17	1.5	0.037	0.849
	102		25.1	5.8	17	1.4		
		Calibre*Stick						
Elbow flexion/extension max (°)	LC	77	58.2	7.9	8	2.8	0.031	0.862
		102	61.5	12.6	8	4.5		
	HC	77	55.2	20.3	9	6.8		
		102	56.5	22.6	9	7.5		
Grip width max (mm)	LC	77	879.1	161.8	8	57.2	1.945	0.173
		102	797.4	59.1	8	20.9		
	HC	77	797.2	55.5	9	18.5		
		102	811.3	91.9	9	30.6		

Lower hand placement max (mm)	LC	77	707.3	82.1	8	29.0	1.521	0.227
		102	729.6	72.9	8	25.8		
	HC	77	728.8	50.0	9	16.7		
		102	695.7	54.9	9	18.3		
Stance width max (°)	LC	77	2622.9	4882.7	8	1726.3	1.172	0.288
		102	866.9	141.5	8	50.0		
	HC	77	893.4	94.2	9	31.4		
		102	893.3	86.1	9	28.7		
Wrist flexion/extension max (°)	LC	77	0.2	7.9	8	2.8	0.174	0.680
		102	3.2	9.9	8	3.5		
	HC	77	-1.6	10.3	9	3.4		
		102	-1.2	7.1	9	2.4		
Radial/ulnar deviation max (°)	LC	77	144.3	34.8	8	12.3	0.015	0.904
		102	146.8	29.1	8	10.3		
	HC	77	149.4	28.0	9	9.3		
		102	149.2	33.7	9	11.2		
Forearm pronation/supination max (°)	LC	77	139.0	24.7	8	8.7	0.136	0.715
		102	143.8	23.8	8	8.4		
	HC	77	132.9	41.4	9	13.8		
		102	146.3	38.6	9	12.9		
Blade pitch max (°)	LC	77	108.1	8.6	8	3.1	1.510	0.229
		102	105.4	9.9	8	3.5		
	HC	77	98.4	6.0	9	2.0		
		102	102.4	7.0	9	2.3		
Blade roll max (°)	LC	77	115.3	16.0	8	5.7	0.042	0.840
		102	113.6	14.8	8	5.2		
	HC	77	121.0	33.2	9	11.1		
		102	123.4	40.4	9	13.5		
Stick bend max (°)	LC	77	12.7	21.2	8	7.5	0.002	0.965
		102	13.7	17.9	8	6.3		
	HC	77	14.9	13.4	9	4.5		
		102	15.4	9.2	9	3.1		
Blade yaw max (°)	LC	77	79.1	11.0	8	3.9	1.262	0.270
		102	83.1	12.2	8	4.3		
	HC	77	82.0	15.1	9	5.0		
		102	77.0	6.7	9	2.2		
SG1 max (με)	LC	77	2874.3	931.0	8	329.2	1.471	0.235
		102	2673.6	874.6	8	309.2		
	HC	77	4072.3	515.5	9	171.8		
		102	3219.3	777.2	9	259.1		
SG2 max (με)	LC	77	3971.6	1018.9	8	360.2	0.005	0.942
		102	3400.7	1780.9	8	629.6		
	HC	77	5153.0	1147.5	9	382.5		
		102	4648.3	1206.5	9	402.2		
SG3 max (με)	LC	77	2722.0	833.3	8	294.6	0.974	0.332

		102	2471.1	715.0	8	252.8		
	HC	77	4122.4	735.7	9	245.2		
		102	3352.8	773.0	9	257.7		
SG4 max (με)	LC	77	2014.5	574.6	8	203.2	0.746	0.395
		102	1791.8	424.3	8	150.0		
	HC	77	2976.7	526.6	9	175.5		
		102	2449.4	513.8	9	171.3		
SG5 max (με)	LC	77	1842.8	974.1	8	344.4	0.007	0.936
		102	1336.9	226.7	8	80.1		
	HC	77	2228.9	299.5	9	99.8		
		102	1693.4	298.7	9	99.6		
Max Puck Velocity (m/s)	LC	77	22.3	7.3	8	2.6	0.008	0.928
		102	22.5	6.3	8	2.2		
	HC	77	26.9	4.0	9	1.3		
		102	27.4	4.5	9	1.5		
		Times						
		Calibre						
SG1 time to peak strain (ms)	LC		348.0	316.2	16	79.1	14.490	0.001
	HC		53.2	40.0	18	9.4		
SG2 time to peak strain (ms)	LC		348.5	317.3	16	79.3	14.337	0.001
	HC		54.3	39.5	18	9.3		
SG3 time to peak strain (ms)	LC		349.0	317.3	16	79.3	14.210	0.001
	HC		56.2	38.9	18	9.2		
SG4 time to peak strain (ms)	LC		349.5	317.9	16	79.5	14.225	0.001
	HC		56.1	39.3	18	9.3		
SG5 time to peak strain (ms)	LC		347.1	315.4	16	78.8	14.273	0.001
	HC		55.4	38.6	18	9.1		
SG1 avg load rate IC to peak (με/ms)	LC		4.5	4.5	16	0.3	12.859	0.011
	HC		10.0	4.1	18	0.2		
SG2 avg load rate IC to peak (με/ms)	LC		6.9	5.1	16	0.3	10.235	0.003
	HC		12.9	5.7	18	0.3		
SG3 avg load rate IC to peak (με/ms)	LC		3.8	3.6	16	0.2	17.093	0.000
	HC		9.2	3.7	18	0.2		
SG4 avg load rateIC to peak (με/ms)	LC		2.8	2.6	16	0.2	18.553	0.000
	HC		6.7	2.6	18	0.1		
SG5 avg load rate IC to peak (με/ms)	LC		2.6	2.8	16	0.2	8.392	0.007
	HC		5.3	2.5	18	0.1		
SG1 avg decay rate peak to PR (με/ms)	LC		-5.7	2.1	16	0.1	11.023	0.002
	HC		-10.0	4.2	18	0.2		
SG2 avg decay rate peak to PR (με/ms)	LC		-5.4	4.9	16	0.3	15.603	0.000
	HC		-14.0	7.0	18	0.4		

SG3 avg decay rate peak to PR (με/ms)	LC	-3.5	5.9	16	0.4	15.297	0.000
	HC	-11.2	5.3	18	0.3		
SG4 avg decay rate peak to PR (με/ms)	LC	-2.8	3.4	16	0.2	16.758	0.000
	HC	-7.9	3.7	18	0.2		
SG5 avg decay rate peak to PR (με/ms)	LC	-2.6	3.9	16	0.2	7.444	0.011
	HC	-5.6	2.7	18	0.1		
Blade-ice contact from IC-PC (ms)	LC	349.3	298.8	16	74.7	10.771	0.003
	HC	84.9	136.1	18	32.1		
Shot time from IC- PR (ms)	LC	429.0	287.9	16	72.0	13.340	0.001
	HC	142.6	138.1	18	32.6		
Blade-puck contact time from PC-PR (ms)	LC	79.7	21.4	16	5.4	12.408	0.001
	HC	57.8	13.7	18	3.2		
		Stick					
SG1 time to peak strain (ms)	77	186.3	253.1	17	61.4	0.025	0.875
	102	197.6	278.1	17	67.4		
SG2 time to peak strain (ms)	77	187.4	253.5	17	61.5	0.022	0.883
	102	198.0	278.4	17	67.5		
SG3 time to peak strain (ms)	77	188.8	253.0	17	61.4	0.021	0.885
	102	199.2	278.0	17	67.4		
SG4 time to peak strain (ms)	77	188.1	252.5	17	61.2	0.028	0.868
	102	200.2	279.6	17	67.8		
SG5 time to peak strain (ms)	77	187.1	250.2	17	60.7	0.025	0.875
	102	198.3	277.9	17	67.4		
SG1 avg load rate IC to peak (με/ms)	77	7.5	5.0	17	0.3	0.029	0.892
	102	7.3	5.3	17	0.3		
SG2 avg load rate IC to peak (με/ms)	77	9.1	6.4	17	0.4	1.028	0.319
	102	11.0	6.1	17	0.4		
SG3 avg load rate IC to peak (με/ms)	77	6.6	4.5	17	0.3	0.001	0.978
	102	6.6	4.7	17	0.3		
SG4 avg load rateIC to peak (με/ms)	77	4.9	3.3	17	0.2	0.004	0.952
	102	4.8	3.3	17	0.2		
SG5 avg load rate IC to peak (με/ms)	77	4.4	3.4	17	0.2	0.688	0.413
	102	3.6	2.5	17	0.1		
SG1 avg decay rate peak to PR (με/ms)	77	-8.8	4.4	17	0.3	1.412	0.244
	102	-7.2	4.1	17	0.2		
SG2 avg decay rate peak to PR (με/ms)	77	-10.1	8.4	17	0.5	0.024	0.877
	102	-9.8	6.6	17	0.4		
SG3 avg decay rate peak to PR (με/ms)	77	-7.4	8.3	17	0.5	0.067	0.797
	102	-7.8	4.8	17	0.3		

SG4 avg decay rate peak to PR (με/ms)	77		-6.3	3.7	17	0.2	1.532	0.225
	102		-4.8	5.0	17	0.3		
SG5 avg decay rate peak to PR (με/ms)	77		-5.3	2.9	17	0.2	4.759	0.037
	102		-3.0	3.9	17	0.2		
Blade-ice contact from IC-PC (ms)	77		201.1	249.9	17	60.6	0.045	0.834
	102		217.5	278.9	17	67.6		
Shot time from IC- PR (ms)	77		267.4	251.6	17	61.0	0.071	0.792
	102		287.4	279.0	17	67.7		
Blade-puck contact time from PC-PR (ms)	77		66.3	20.0	17	4.9	0.380	0.542
	102		69.9	21.8	17	5.3		
		Calibre*Stick						
SG1 time to peak strain (ms)	LC	77	333.9	312.8	8	110.6	0.043	0.838
		102	362.1	340.6	8	120.4		
	HC	77	55.1	37.3	9	12.4		
		102	51.3	44.7	9	14.9		
SG2 time to peak strain (ms)	LC	77	335.0	313.7	8	110.9	0.040	0.843
		102	362.0	342.0	8	120.9		
	HC	77	56.3	36.9	9	12.3		
		102	52.3	44.2	9	14.7		
SG3 time to peak strain (ms)	LC	77	335.7	313.5	8	110.8	0.038	0.846
		102	362.2	342.1	8	121.0		
	HC	77	58.2	35.9	9	12.0		
		102	54.3	43.8	9	14.6		
SG4 time to peak strain (ms)	LC	77	334.5	312.9	8	110.6	0.047	0.829
		102	364.5	343.7	8	121.5		
	HC	77	58.0	36.5	9	12.2		
		102	54.1	44.0	9	14.7		
SG5 time to peak strain (ms)	LC	77	332.8	309.2	8	109.3	0.045	0.834
		102	361.3	342.2	8	121.0		
	HC	77	57.5	37.1	9	12.4		
		102	53.4	42.3	9	14.1		
SG1 avg load rate IC to peak (με/ms)	LC	77	4.5	4.7	8	0.6	0.029	0.867
		102	4.5	4.7	8	0.6		
	HC	77	10.2	3.6	9	0.4		
		102	9.7	4.7	9	0.5		
SG2 avg load rate IC to peak (με/ms)	LC	77	5.3	5.0	8	0.6	0.353	0.557
		102	8.4	5.1	8	0.6		
	HC	77	12.5	5.6	9	0.6		
		102	13.3	6.1	9	0.7		
SG3 avg load rate IC to peak (με/ms)	LC	77	3.5	3.5	8	0.4	0.109	0.744
		102	4.0	4.0	8	0.5		
	HC	77	9.4	3.5	9	0.4		

		102	9.0	4.1	9	0.5		
SG4 avg load rateIC to peak (με/ms)	LC	77	2.7	2.6	8	0.3	0.063	0.804
		102	2.9	2.8	8	0.4		
	HC	77	6.9	2.5	9	0.3		
		102	6.6	2.8	9	0.3		
SG5 avg load rate IC to peak (με/ms)	LC	77	2.7	3.1	8	0.4	0.544	0.467
		102	2.6	2.8	8	0.4		
	HC	77	6.0	3.0	9	0.3		
		102	4.6	1.7	9	0.2		
SG1 avg decay rate peak to PR (με/ms)	LC	77	-6.4	2.3	8	0.3	0.013	0.910
		102	-5.1	1.6	8	0.2		
	HC	77	-10.8	4.8	9	0.5		
		102	-9.2	4.7	9	0.5		
SG2 avg decay rate peak to PR (με/ms)	LC	77	-5.5	6.9	8	0.9	0.004	0.948
		102	-5.3	1.6	8	0.2		
	HC	77	-14.2	7.6	9	0.8		
		102	-13.7	6.9	9	0.8		
SG3 avg decay rate peak to PR (με/ms)	LC	77	-2.3	8.2	8	1.0	1.003	0.325
		102	-4.8	1.5	8	0.2		
	HC	77	-11.9	5.6	9	0.6		
		102	-10.4	5.2	9	0.6		
SG4 avg decay rate peak to PR (με/ms)	LC	77	-3.9	1.2	8	0.2	0.288	0.596
		102	-1.7	4.6	8	0.6		
	HC	77	-8.3	3.9	9	0.4		
		102	-7.5	3.7	9	0.4		
SG5 avg decay rate peak to PR (με/ms)	LC	77	-4.4	2.9	8	0.4	1.275	0.268
		102	-0.8	4.2	8	0.5		
	HC	77	-6.2	2.9	9	0.3		
		102	-5.0	2.5	9	0.3		
Blade-ice contact from IC-PC (ms)	LC	77	335.2	302.2	8	106.9	0.020	0.890
		102	363.5	315.4	8	111.5		
	HC	77	82.0	105.2	9	35.1		
		102	87.7	168.2	9	56.1		
Shot time from IC- PR (ms)	LC	77	410.9	295.8	8	104.6	0.038	0.846
		102	447.1	298.9	8	105.7		
	HC	77	139.9	105.7	9	35.2		
		102	145.4	171.3	9	57.1		
Blade-puck contact time from PC-PR (ms)	LC	77	75.7	24.0	8	8.5	0.430	0.517
		102	83.6	19.2	8	6.8		
	HC	77	57.9	11.3	9	3.8		
		102	57.7	16.4	9	5.5		

Wrist Shot							
	Condition	M	SD	n	SE	F	*p*
		PC					
		Calibre					
Elbow flexion/extension at PC (°)	LC	51.5	14.4	16	3.6	1.609	0.214
	HC	46.2	9.1	18	2.2		
Grip width at PC (mm)	LC	553.8	37.1	16	9.3	1.453	0.237
	HC	578.8	72.6	18	17.1		
Lower hand placement at PC (mm)	LC	901.8	49.9	16	12.5	0.996	0.326
	HC	880.4	68.7	18	16.2		
Stance width at PC (mm)	LC	686.6	122.7	16	30.7	2.553	0.121
	HC	745.5	85.8	18	20.2		
Wrist flexion/extension at PC (°)	LC	-19.2	19.0	16	4.7	0.213	0.648
	HC	-16.9	7.8	18	1.8		
Radial/ulnar deviation at PC (°)	LC	129.6	34.5	16	8.6	0.056	0.814
	HC	127.2	22.1	18	5.2		
Forearm pronation/supination at PC (°)	LC	120.9	39.2	16	9.8	0.017	0.898
	HC	122.8	40.9	18	9.6		
Blade pitch at PC (°)	LC	85.4	23.0	16	5.7	0.939	0.340
	HC	93.8	25.4	18	6.0		
Blade roll at PC (°)	LC	96.8	31.8	16	8.0	0.863	0.360
	HC	86.3	31.9	18	7.5		
Stick bend at PC (°)	LC	1.1	0.8	16	0.2	0.005	0.944
	HC	1.1	0.4	18	0.1		
Blade yaw at PC (°)	LC	53.4	4.0	16	1.0	0.540	0.468
	HC	54.6	5.5	18	1.3		
SG1 at PC (με)	LC	326.9	446.9	16	111.7	0.932	0.342
	HC	201.2	280.3	18	66.1		
SG2 at PC (με)	LC	497.3	829.0	16	207.2	1.658	0.208
	HC	221.2	304.6	18	71.8		
SG3 at PC (με)	LC	182.9	240.0	16	60.0	0.177	0.677
	HC	151.1	186.3	18	43.9		
SG4 at PC (με)	LC	123.1	156.4	16	39.1	0.124	0.727
	HC	105.5	125.8	18	29.7		
SG5 at PC (με)	LC	90.8	94.2	16	23.6	0.246	0.624
	HC	74.6	90.5	18	21.3		
		Stick					
Elbow flexion/extension at PC (°)	77	50.1	13.4	17	3.2	0.495	0.487
	102	47.3	10.7	17	2.6		
Grip width at PC (mm)	77	569.5	57.1	17	13.8	0.067	0.798
	102	564.6	62.8	17	15.2		
Lower hand placement at PC (mm)	77	886.9	59.1	17	14.3	0.121	0.731
	102	894.0	63.9	17	15.5		
Stance width at PC (mm)	77	726.9	89.8	17	21.8	0.223	0.640

	102		708.6	124.6	17	30.2		
Wrist flexion/extension at PC (°)	77		-18.4	14.0	17	3.4	0.025	0.874
	102		-17.5	14.5	17	3.5		
Radial/ulnar deviation at PC (°)	77		131.1	29.2	17	7.1	0.331	0.569
	102		125.5	27.7	17	6.7		
Forearm pronation/supination at PC (°)	77		124.9	42.1	17	10.2	0.183	0.672
	102		118.9	37.7	17	9.1		
Blade pitch at PC (°)	77		91.0	26.2	17	6.4	0.063	0.804
	102		88.8	23.0	17	5.6		
Blade roll at PC (°)	77		90.3	33.9	17	8.2	0.028	0.869
	102		92.2	30.7	17	7.4		
Stick bend at PC (°)	77		1.2	0.7	17	0.2	2.316	0.139
	102		0.9	0.5	17	0.1		
Blade yaw at PC (°)	77		55.1	4.9	17	1.2	1.564	0.221
	102		53.0	4.7	17	1.1		
SG1 at PC (με)	77		286.7	449.2	17	109.0	0.165	0.688
	102		234.0	275.4	17	66.8		
SG2 at PC (με)	77		294.1	501.1	17	121.5	0.315	0.579
	102		408.3	724.7	17	175.8		
SG3 at PC (με)	77		178.4	252.9	17	61.3	0.105	0.748
	102		153.8	164.6	17	39.9		
SG4 at PC (με)	77		119.7	164.6	17	39.9	0.056	0.814
	102		107.9	112.9	17	27.4		
SG5 at PC (με)	77		85.3	107.7	17	26.1	0.031	0.861
	102		79.1	74.5	17	18.1		
Calibre*Stick								
Elbow flexion/extension at PC (°)	LC	77	54.6	16.4	8	5.8	0.670	0.420
		102	48.3	12.3	8	4.4		
	HC	77	46.0	9.1	9	3.0		
		102	46.5	9.7	9	3.2		
Grip width at PC (mm)	LC	77	559.9	42.0	8	14.9	0.111	0.741
		102	547.7	33.3	8	11.8		
	HC	77	578.1	69.3	9	23.1		
		102	579.6	79.9	9	26.6		
Lower hand placement at PC (mm)	LC	77	894.9	54.8	8	19.4	0.086	0.771
		102	908.6	47.2	8	16.7		
	HC	77	879.8	65.1	9	21.7		
		102	880.9	76.2	9	25.4		
Stance width at PC (mm)	LC	77	687.9	89.6	8	31.7	0.161	0.691
		102	685.3	155.6	8	55.0		
	HC	77	761.7	78.9	9	26.3		
		102	729.4	93.9	9	31.3		
Wrist flexion/extension at PC (°)	LC	77	-19.4	19.9	8	7.0	0.004	0.953
		102	-18.9	19.4	8	6.9		
	HC	77	-17.4	6.7	9	2.2		

		102	-16.3	9.2	9	3.1		
Radial/ulnar deviation at PC (°)	LC	77	134.2	36.5	8	12.9	0.121	0.730
		102	124.9	34.1	8	12.1		
	HC	77	128.4	22.7	9	7.6		
		102	126.1	22.8	9	7.6		
Forearm pronation/supination at PC (°)	LC	77	124.7	42.1	8	14.9	0.011	0.916
		102	117.2	38.5	8	13.6		
	HC	77	125.1	44.8	9	14.9		
		102	120.5	39.2	9	13.1		
Blade pitch at PC (°)	LC	77	86.4	23.7	8	8.4	0.001	0.978
		102	84.5	23.9	8	8.4		
	HC	77	95.0	29.1	9	9.7		
		102	92.6	22.9	9	7.6		
Blade roll at PC (°)	LC	77	95.9	33.1	8	11.7	0.000	0.996
		102	97.8	32.8	8	11.6		
	HC	77	85.4	35.8	9	11.9		
		102	87.2	29.7	9	9.9		
Stick bend at PC (°)	LC	77	1.2	0.9	8	0.3	0.007	0.935
		102	0.9	0.6	8	0.2		
	HC	77	1.2	0.3	9	0.1		
		102	0.9	0.4	9	0.1		
Blade yaw at PC (°)	LC	77	54.6	4.6	8	1.6	0.013	0.909
		102	52.3	3.2	8	1.1		
	HC	77	55.6	5.3	9	1.8		
		102	53.7	5.9	9	2.0		
SG1 at PC (με)	LC	77	355.2	534.0	8	188.8	0.001	0.977
		102	298.6	375.6	8	132.8		
	HC	77	225.7	381.1	9	127.0		
		102	176.7	142.8	9	47.6		
SG2 at PC (με)	LC	77	385.8	620.2	8	219.3	0.230	0.635
		102	608.9	1029.3	8	363.9		
	HC	77	212.5	386.9	9	129.0		
		102	229.9	217.5	9	72.5		
SG3 at PC (με)	LC	77	194.4	286.7	8	101.3	0.000	0.984
		102	171.4	202.3	8	71.5		
	HC	77	164.2	235.7	9	78.6		
		102	138.1	133.4	9	44.5		
SG4 at PC (με)	LC	77	129.4	182.5	8	64.5	0.000	0.990
		102	116.9	138.0	8	48.8		
	HC	77	111.1	157.8	9	52.6		
		102	99.9	93.1	9	31.0		
SG5 at PC (με)	LC	77	90.1	105.3	8	37.2	0.046	0.831
		102	91.4	89.1	8	31.5		
	HC	77	81.0	116.0	9	38.7		
		102	68.2	62.1	9	20.7		

PR							
Calibre							
Elbow flexion/extension at PR (°)	LC	50.1	10.8	16	2.7	1.578	0.219
	HC	46.0	7.8	18	1.8		
Grip width at PR (mm)	LC	561.7	36.5	16	9.1	2.842	0.102
	HC	593.6	64.8	18	15.3		
Lower hand placement at PR (mm)	LC	898.5	49.4	16	12.4	0.618	0.438
	HC	881.8	67.4	18	15.9		
Stance width at PR (mm)	LC	760.6	142.2	16	35.5	9.343	0.005
	HC	889.8	97.5	18	23.0		
Wrist flexion/extension at PR (°)	LC	-17.8	12.1	16	3.0	5.446	0.027
	HC	-10.5	7.1	18	1.7		
Radial/ulnar deviation at PR (°)	LC	129.0	30.1	16	7.5	0.005	0.942
	HC	128.3	27.1	18	6.4		
Forearm pronation/supination at PR(°)	LC	117.9	27.7	16	6.9	0.015	0.903
	HC	116.6	33.1	18	7.8		
Blade pitch at PR (°)	LC	90.6	10.0	16	2.5	0.226	0.638
	HC	92.3	10.7	18	2.5		
Blade roll at PR (°)	LC	90.3	13.4	16	3.3	0.518	0.477
	HC	86.9	13.8	18	3.3		
Stick bend at PR (°)	LC	1.6	0.8	16	0.2	0.569	0.457
	HC	1.4	0.8	18	0.2		
Blade yaw at PR (°)	LC	64.0	7.7	16	1.9	0.146	0.705
	HC	63.2	2.8	18	0.7		
SG1 at PR (με)	LC	231.8	665.6	16	166.4	0.288	0.595
	HC	134.4	353.5	18	83.3		
SG2 at PR (με)	LC	503.8	995.2	16	248.8	1.627	0.212
	HC	191.0	350.6	18	82.6		
SG3 at PR (με)	LC	163.7	379.2	16	94.8	0.018	0.895
	HC	149.3	235.0	18	55.4		
SG4 at PR (με)	LC	121.6	246.0	16	61.5	0.001	0.976
	HC	119.4	164.1	18	38.7		
SG5 at PR (με)	LC	89.2	163.7	16	40.9	0.094	0.761
	HC	104.7	129.9	18	30.6		
Stick							
Elbow flexion/extension at PR (°)	77	48.1	9.7	17	2.3	0.007	0.934
	102	47.8	9.5	17	2.3		
Grip width at PR (mm)	77	579.0	53.5	17	13.0	0.003	0.958
	102	578.2	58.2	17	14.1		
Lower hand placement at PR (mm)	77	890.3	57.2	17	13.9	0.002	0.966
	102	889.1	63.2	17	15.3		
Stance width at PR (mm)	77	843.7	106.3	17	25.8	0.528	0.473
	102	814.3	161.7	17	39.2		
Wrist flexion/extension at PR (°)	77	-11.3	7.6	17	1.8	3.234	0.082
	102	-16.6	12.0	17	2.9		

Radial/ulnar deviation at PR (°)	77		131.1	29.2	17	7.1	0.249	0.622
	102		126.2	27.6	17	6.7		
Forearm pronation/supination at PR(°)	77		116.7	30.3	17	7.4	0.007	0.934
	102		117.7	31.0	17	7.5		
Blade pitch at PR (°)	77		91.9	9.9	17	2.4	0.041	0.841
	102		91.0	10.9	17	2.6		
Blade roll at PR (°)	77		88.0	13.1	17	3.2	0.013	0.910
	102		88.9	14.3	17	3.5		
Stick bend at PR (°)	77		1.7	0.8	17	0.2	2.346	0.136
	102		1.3	0.8	17	0.2		
Blade yaw at PR (°)	77		64.2	6.3	17	1.5	0.422	0.521
	102		63.0	5.0	17	1.2		
SG1 at PR (με)	77		153.8	404.4	17	98.1	0.130	0.721
	102		206.7	623.0	17	151.1		
SG2 at PR (με)	77		217.0	441.5	17	107.1	1.160	0.290
	102		459.3	940.6	17	228.1		
SG3 at PR (με)	77		150.5	268.0	17	65.0	0.030	0.864
	102		161.6	348.8	17	84.6		
SG4 at PR (με)	77		114.9	183.4	17	44.5	0.053	0.820
	102		126.0	227.2	17	55.1		
SG5 at PR (με)	77		93.6	145.6	17	35.3	0.054	0.817
	102		101.2	148.2	17	35.9		
Calibre*Stick								
Elbow flexion/extension at PR (°)	LC	77	50.3	10.2	8	3.6	0.001	0.981
		102	49.9	12.1	8	4.3		
	HC	77	46.1	9.3	9	3.1		
		102	45.9	6.6	9	2.2		
Grip width at PR (mm)	LC	77	563.8	40.6	8	14.3	0.029	0.866
		102	559.5	34.6	8	12.2		
	HC	77	592.5	62.0	9	20.7		
		102	594.7	71.3	9	23.8		
Lower hand placement at PR (mm)	LC	77	896.4	54.2	8	19.2	0.055	0.817
		102	900.5	47.8	8	16.9		
	HC	77	884.8	62.4	9	20.8		
		102	878.9	75.8	9	25.3		
Stance width at PR (mm)	LC	77	786.4	98.4	8	34.8	0.244	0.625
		102	734.8	179.2	8	63.4		
	HC	77	894.7	88.8	9	29.6		
		102	884.9	110.7	9	36.9		
Wrist flexion/extension at PR (°)	LC	77	-11.9	6.8	8	2.4	3.961	0.056
		102	-23.7	13.6	8	4.8		
	HC	77	-10.8	8.6	9	2.9		
		102	-10.2	5.7	9	1.9		
Radial/ulnar deviation at PR (°)	LC	77	133.2	31.3	8	11.1	0.107	0.745
		102	124.9	30.4	8	10.7		

	HC	77	129.2	29.0	9	9.7		
		102	127.4	26.8	9	8.9		
Forearm pronation/supination at PR(°)	LC	77	118.9	23.4	8	8.3	0.070	0.793
		102	116.9	33.0	8	11.7		
	HC	77	114.7	36.8	9	12.3		
		102	118.5	31.0	9	10.3		
Blade pitch at PR (°)	LC	77	88.9	9.3	8	3.3	1.213	0.279
		102	92.2	11.1	8	3.9		
	HC	77	94.6	10.0	9	3.3		
		102	89.9	11.3	9	3.8		
Blade roll at PR (°)	LC	77	92.6	12.5	8	4.4	1.242	0.274
		102	87.9	14.7	8	5.2		
	HC	77	84.0	12.9	9	4.3		
		102	89.8	14.9	9	5.0		
Stick bend at PR (°)	LC	77	1.7	0.8	8	0.3	1.401	0.246
		102	1.6	0.9	8	0.3		
	HC	77	1.8	0.9	9	0.3		
		102	1.0	0.6	9	0.2		
Blade yaw at PR (°)	LC	77	64.9	8.8	8	3.1	0.093	0.763
		102	63.0	7.0	8	2.5		
	HC	77	63.6	3.3	9	1.1		
		102	62.9	2.5	9	0.8		
SG1 at PR (με)	LC	77	92.8	431.5	8	152.6	1.373	0.250
		102	370.8	848.0	8	299.8		
	HC	77	208.0	396.4	9	132.1		
		102	60.8	310.1	9	103.4		
SG2 at PR (με)	LC	77	186.5	523.8	8	185.2	2.282	0.141
		102	821.1	1272.0	8	449.7		
	HC	77	244.2	384.8	9	128.3		
		102	137.8	326.7	9	108.9		
SG3 at PR (με)	LC	77	90.3	273.3	8	96.6	1.414	0.244
		102	237.1	470.2	8	166.2		
	HC	77	204.1	267.2	9	89.1		
		102	94.5	197.8	9	65.9		
SG4 at PR (με)	LC	77	68.3	189.3	8	66.9	1.600	0.216
		102	174.9	295.5	8	104.5		
	HC	77	156.4	178.4	9	59.5		
		102	82.4	149.3	9	49.8		
SG5 at PR (με)	LC	77	48.5	143.2	8	50.6	1.898	0.178
		102	129.8	182.1	8	64.4		
	HC	77	133.6	143.6	9	47.9		
		102	75.8	115.6	9	38.5		
			Δ PC-PR					
			Calibre					
Elbow flexion/extension Δ PC-PR (°)	LC		-1.1	16.1	16	4.0	0.032	0.858

	HC	-0.3	9.2	18	2.2		
Grip width Δ PC-PR (mm)	LC	8.9	13.2	16	3.3	1.375	0.250
	HC	13.8	10.5	18	2.5		
Lower hand placement Δ PC-PR (mm)	LC	-3.3	26.2	16	6.6	0.473	0.497
	HC	1.5	12.2	18	2.9		
Stance width Δ PC-PR (mm)	LC	83.1	137.5	16	34.4	2.212	0.147
	HC	140.3	75.9	18	17.9		
Wrist flexion/extension Δ PC-PR (°)	LC	1.5	21.8	16	5.4	0.667	0.421
	HC	6.2	10.7	18	2.5		
Radial/ulnar deviation Δ PC-PR (°)	LC	-1.5	20.4	16	5.1	0.187	0.669
	HC	1.1	13.2	18	3.1		
Forearm pronation/supination Δ PC-PR (°)	LC	-2.5	36.9	16	9.2	0.145	0.706
	HC	-6.2	15.8	18	3.7		
Blade pitch Δ PC-PR (°)	LC	5.0	30.0	16	7.5	0.345	0.561
	HC	-1.5	32.8	18	7.7		
Blade roll Δ PC-PR (°)	LC	-6.6	39.4	16	9.8	0.235	0.631
	HC	0.5	42.7	18	10.1		
Stick bend Δ PC-PR (°)	LC	0.5	1.0	16	0.3	0.350	0.559
	HC	0.3	0.9	18	0.2		
Blade yaw Δ PC-PR (°)	LC	10.6	9.1	16	2.3	0.473	0.497
	HC	8.6	6.9	18	1.6		
SG1 Δ PC-PR (με)	LC	-95.1	672.1	16	168.0	0.021	0.886
	HC	-66.8	447.0	18	105.4		
SG2 Δ PC-PR (με)	LC	817.6	3187.5	16	796.9	1.312	0.261
	HC	-30.3	450.1	18	106.1		
SG3 Δ PC-PR (με)	LC	-19.2	377.1	16	94.3	0.023	0.879
	HC	-1.9	274.5	18	64.7		
SG4 Δ PC-PR (με)	LC	-1.5	239.8	16	60.0	0.043	0.836
	HC	13.9	189.1	18	44.6		
SG5 Δ PC-PR (με)	LC	-1.6	157.2	16	39.3	0.359	0.554
	HC	30.1	148.9	18	35.1		
Stick							
Elbow flexion/extension Δ PC-PR (°)	77	-1.8	14.9	17	3.6	0.273	0.605
	102	0.4	10.5	17	2.5		
Grip width Δ PC-PR (mm)	77	10.5	14.2	17	3.5	0.304	0.585
	102	12.5	9.4	17	2.3		
Lower hand placement Δ PC-PR (mm)	77	3.4	25.3	17	6.1	1.449	0.238
	102	-4.9	11.8	17	2.9		
Stance width Δ PC-PR (mm)	77	116.9	96.0	17	23.3	0.050	0.824
	102	109.9	127.9	17	31.0		
Wrist flexion/extension Δ PC-PR (°)	1	7.2	16.4	17	4.0	1.347	0.255
	2	0.9	16.9	17	4.1		
Radial/ulnar deviation Δ PC-PR (°)	77	-0.9	16.0	17	3.9	0.082	0.776
	102	0.7	17.9	17	4.3		

Forearm pronation/supination Δ PC-PR (°)	77		-7.7	32.6	17	7.9	0.433	0.515
	102		-1.2	21.4	17	5.2		
Blade pitch Δ PC-PR (°)	77		0.9	31.8	17	7.7	0.020	0.890
	102		2.2	31.5	17	7.6		
Blade roll Δ PC-PR (°)	77		-2.3	40.7	17	9.9	0.010	0.922
	102		-3.4	41.9	17	10.2		
Stick bend Δ PC-PR (°)	77		0.5	0.9	17	0.2	0.104	0.750
	102		0.4	0.9	17	0.2		
Blade yaw Δ PC-PR (°)	77		9.1	8.5	17	2.1	0.082	0.777
	102		10.0	7.6	17	1.8		
SG1 Δ PC-PR (με)	77		-132.9	492.1	17	119.3	0.367	0.549
	102		-27.4	623.0	17	151.1		
SG2 Δ PC-PR (με)	77		-77.0	465.6	17	112.9	1.665	0.207
	102		814.5	3079.3	17	746.8		
SG3 Δ PC-PR (με)	77		-27.9	276.9	17	67.2	0.145	0.706
	102		7.8	369.1	17	89.5		
SG4 Δ PC-PR (με)	77		-4.8	183.6	17	44.5	0.145	0.706
	102		18.1	241.0	17	58.5		
SG5 Δ PC-PR (με)	77		8.3	149.0	17	36.1	0.109	0.743
	102		22.1	158.0	17	38.3		
Calibre*Stick								
Elbow flexion/extension Δ PC-PR (°)	LC	77	-3.8	19.0	8	6.7	0.456	0.505
		102	1.6	13.3	8	4.7		
	HC	77	0.1	10.9	9	3.6		
		102	-0.6	7.8	9	2.6		
Grip width Δ PC-PR (mm)	LC	77	6.0	16.4	8	5.8	0.752	0.393
		102	11.9	9.1	8	3.2		
	HC	77	14.4	11.5	9	3.8		
		102	13.1	10.2	9	3.4		
Lower hand placement Δ PC-PR (mm)	LC	77	1.6	34.7	8	12.3	0.038	0.847
		102	-8.2	14.8	8	5.2		
	HC	77	5.0	14.9	9	5.0		
		102	-2.0	8.2	9	2.7		
Stance width Δ PC-PR (mm)	LC	77	101.2	124.9	8	44.2	0.512	0.480
		102	65.1	155.5	8	55.0		
	HC	77	130.8	65.5	9	21.8		
		102	149.7	88.1	9	29.4		
Wrist flexion/extension Δ PC-PR (°)	LC	77	7.9	20.6	8	7.3	1.085	0.306
		102	-4.8	22.4	8	7.9		
	HC	77	6.6	12.9	9	4.3		
		102	5.9	8.6	9	2.9		
Radial/ulnar deviation Δ PC-PR (°)	LC	77	-2.8	16.6	8	5.9	0.031	0.862
		102	-0.1	24.7	8	8.7		
	HC	77	0.8	16.2	9	5.4		
		102	1.5	10.2	9	3.4		

Forearm pronation/supination Δ PC-PR (°)	LC	77	-4.7	46.6	8	16.5	0.040	0.843
		102	-0.2	26.9	8	9.5		
	HC	77	-10.4	14.5	9	4.8		
		102	-2.0	16.8	9	5.6		
Blade pitch Δ PC-PR (°)	LC	77	2.3	29.1	8	10.3	0.122	0.729
		102	7.8	32.6	8	11.5		
	HC	77	-0.3	35.8	9	11.9		
		102	-2.7	31.6	9	10.5		
Blade roll Δ PC-PR (°)	LC	77	-3.1	37.7	8	13.3	0.142	0.709
		102	-10.0	43.2	8	15.3		
	HC	77	-1.5	45.5	9	15.2		
		102	2.5	42.3	9	14.1		
Stick bend Δ PC-PR (°)	LC	77	0.4	1.0	8	0.3	1.105	0.302
		102	0.6	1.1	8	0.4		
	HC	77	0.6	1.0	9	0.3		
		102	0.1	0.7	9	0.2		
Blade yaw Δ PC-PR (°)	LC	77	10.3	10.1	8	3.6	0.014	0.908
		102	10.8	8.7	8	3.1		
	HC	77	8.0	7.3	9	2.4		
		102	9.2	6.9	9	2.3		
SG1 Δ PC-PR (με)	LC	77	-262.5	400.1	8	141.4	1.229	0.276
		102	72.2	862.5	8	304.9		
	HC	77	-17.7	559.0	9	186.3		
		102	-115.9	326.6	9	108.9		
SG2 Δ PC-PR (με)	LC	77	-199.3	386.8	8	136.7	2.124	0.155
		102	1834.6	4388.5	8	1551.6		
	HC	77	31.6	523.9	9	174.6		
		102	-92.2	384.0	9	128.0		
SG3 Δ PC-PR (με)	LC	77	-104.1	198.3	8	70.1	1.248	0.273
		102	65.7	499.0	8	176.4		
	HC	77	39.9	328.6	9	109.5		
		102	-43.6	219.6	9	73.2		
SG4 Δ PC-PR (με)	LC	77	-61.1	130.6	8	46.2	1.504	0.230
		102	58.0	313.2	8	110.7		
	HC	77	45.3	215.6	9	71.9		
		102	-17.4	165.3	9	55.1		
SG5 Δ PC-PR (με)	LC	77	-41.6	106.8	8	37.7	1.392	0.247
		102	38.4	194.7	8	68.8		
	HC	77	52.6	172.5	9	57.5		
		102	7.6	127.5	9	42.5		
Maxes								
Calibre								
Elbow flexion/extension max (°)	LC		71.7	11.7	16	2.9	0.470	0.498
	HC		76.5	25.8	18	6.1		
Grip width max (mm)	LC		653.9	98.7	16	24.7	0.510	0.481

	HC	629.2	100.4	18	23.7		
Lower hand placement max (mm)	LC	946.8	62.6	16	15.7	2.019	0.166
	HC	910.2	82.2	18	19.4		
Stance width max (°)	LC	858.5	196.2	16	49.0	0.318	0.577
	HC	888.7	100.5	18	23.7		
Wrist flexion/extension max (°)	LC	-0.6	10.5	16	2.6	0.275	0.604
	HC	1.1	8.1	18	1.9		
Radial/ulnar deviation max (°)	LC	152.7	27.3	16	6.8	0.014	0.907
	HC	151.6	26.5	18	6.3		
Forearm pronation/supination max (°)	LC	150.4	30.4	16	7.6	0.001	0.980
	HC	150.1	31.2	18	7.4		
Blade pitch max (°)	LC	115.8	11.5	16	2.9	2.236	0.145
	HC	128.3	30.9	18	7.3		
Blade roll max (°)	LC	126.1	18.6	16	4.6	0.620	0.437
	HC	136.6	48.8	18	11.5		
Stick bend max (°)	LC	8.0	13.7	16	3.4	0.365	0.550
	HC	10.8	13.8	18	3.3		
Blade yaw max (°)	LC	72.4	13.1	16	3.3	0.735	0.398
	HC	76.1	11.6	18	2.7		
SG1 max (με)	LC	2229.2	657.0	16	164.3	17.002	0.000
	HC	3145.1	780.0	18	183.8		
SG2 max (με)	LC	2860.6	1552.1	16	388.0	0.412	0.526
	HC	3144.9	924.6	18	217.9		
SG3 max (με)	LC	1331.1	393.2	16	98.3	18.447	0.000
	HC	1962.6	513.2	18	121.0		
SG4 max (με)	LC	881.5	259.3	16	64.8	18.084	0.000
	HC	1305.4	344.5	18	81.2		
SG5 max (με)	LC	612.4	208.9	16	52.2	11.944	0.002
	HC	856.0	249.1	18	58.7		
Max Puck Velocity (m/s)	LC	20.4	2.9	16	0.7	17.790	0.000
	HC	24.2	2.3	18	0.5		
Stick							
Elbow flexion/extension max (°)	77	79.5	26.2	17	6.4	2.154	0.153
	102	69.0	10.0	17	2.4		
Grip width max (mm)	77	651.9	100.0	17	24.3	0.336	0.566
	102	629.8	99.5	17	24.1		
Lower hand placement max (mm)	77	939.8	82.7	17	20.1	0.915	0.347
	102	915.0	66.3	17	16.1		
Stance width max (°)	77	888.7	172.7	17	41.9	0.337	0.566
	102	860.3	130.5	17	31.6		
Wrist flexion/extension max (°)	77	1.8	8.2	17	2.0	1.080	0.307
	102	-1.3	10.1	17	2.5		
Radial/ulnar deviation max (°)	77	155.7	25.4	17	6.2	0.566	0.458
	102	148.5	27.8	17	6.7		
Forearm pronation/supination max (°)	77	155.0	27.4	17	6.6	0.773	0.386

	102		145.4	33.2	17	8.0		
Blade pitch max (°)	77		124.8	29.1	17	7.1	0.293	0.592
	102		120.1	19.0	17	4.6		
Blade roll max (°)	77		132.5	42.7	17	10.3	0.009	0.927
	102		130.9	33.1	17	8.0		
Stick bend max (°)	77		14.1	18.3	17	4.4	3.958	0.056
	102		4.9	1.5	17	0.4		
Blade yaw max (°)	77		75.2	12.4	17	3.0	0.173	0.681
	102		73.5	12.4	17	3.0		
SG1 max (με)	77		3054.9	944.9	17	229.2	9.098	0.005
	102		2373.3	596.3	17	144.6		
SG2 max (με)	77		3099.3	1070.0	17	259.5	0.132	0.719
	102		2922.9	1431.1	17	347.1		
SG3 max (με)	77		1854.5	618.7	17	150.1	6.406	0.017
	102		1476.3	420.9	17	102.1		
SG4 max (με)	77		1225.1	412.5	17	100.0	5.585	0.025
	102		986.7	289.8	17	70.3		
SG5 max (με)	77		855.7	262.9	17	63.8	10.415	0.003
	102		627.1	203.4	17	49.3		
Max Puck Velocity (m/s)	77		22.8	2.8	17	0.7	0.976	0.331
	102		22.0	3.6	17	0.9		
		Calibre*Stick						
Elbow flexion/extension max (°)	LC	77	74.1	11.9	8	4.2	0.628	0.434
		102	69.4	11.8	8	4.2		
	HC	77	84.3	34.6	9	11.5		
		102	68.7	8.9	9	3.0		
Grip width max (mm)	LC	77	647.0	81.8	8	28.9	0.966	0.334
		102	660.9	118.6	8	41.9		
	HC	77	656.2	118.8	9	39.6		
		102	602.3	75.2	9	25.1		
Lower hand placement max (mm)	LC	77	958.1	75.1	8	26.5	0.005	0.942
		102	935.4	49.8	8	17.6		
	HC	77	923.5	90.1	9	30.0		
		102	896.9	76.4	9	25.5		
Stance width max (°)	LC	77	896.1	235.6	8	83.3	0.681	0.416
		102	821.0	154.2	8	54.5		
	HC	77	882.1	104.9	9	35.0		
		102	895.2	101.7	9	33.9		
Wrist flexion/extension max (°)	LC	77	2.9	7.7	8	2.7	1.401	0.246
		102	-4.1	12.3	8	4.3		
	HC	77	0.8	9.1	9	3.0		
		102	1.3	7.6	9	2.5		
Radial/ulnar deviation max (°)	LC	77	154.9	25.7	8	9.1	0.077	0.783
		102	150.4	30.4	8	10.8		
	HC	77	156.4	26.7	9	8.9		
		102	146.7	27.0	9	9.0		

Forearm pronation/supination max (°)	LC	77	153.5	22.2	8	7.8	0.089	0.767
		102	147.2	38.3	8	13.5		
	HC	77	156.4	32.7	9	10.9		
		102	143.7	30.2	9	10.1		
Blade pitch max (°)	LC	77	116.4	12.8	8	4.5	0.147	0.704
		102	115.1	10.9	8	3.8		
	HC	77	132.2	37.7	9	12.6		
		102	124.5	24.0	9	8.0		
Blade roll max (°)	LC	77	123.7	16.9	8	6.0	0.200	0.658
		102	128.5	21.1	8	7.4		
	HC	77	140.2	57.0	9	19.0		
		102	133.0	42.4	9	14.1		
Stick bend max (°)	LC	77	11.8	19.2	8	6.8	0.116	0.736
		102	4.3	1.3	8	0.5		
	HC	77	16.1	18.4	9	6.1		
		102	5.5	1.6	9	0.5		
Blade yaw max (°)	LC	77	74.1	15.2	8	5.4	0.146	0.705
		102	70.6	11.3	8	4.0		
	HC	77	76.2	10.2	9	3.4		
		102	76.0	13.5	9	4.5		
SG1 max (με)	LC	77	2465.3	764.9	8	270.4	0.793	0.380
		102	1993.1	461.0	8	163.0		
	HC	77	3579.0	785.7	9	261.9		
		102	2711.2	502.1	9	167.4		
SG2 max (με)	LC	77	2809.3	1153.7	8	407.9	0.354	0.556
		102	2911.9	1955.8	8	691.5		
	HC	77	3357.1	982.9	9	327.6		
		102	2932.8	865.5	9	288.5		
SG3 max (με)	LC	77	1466.1	450.2	8	159.2	0.482	0.493
		102	1196.1	294.9	8	104.3		
	HC	77	2199.7	550.8	9	183.6		
		102	1725.5	360.3	9	120.1		
SG4 max (με)	LC	77	975.8	301.4	8	106.6	0.221	0.642
		102	787.1	181.4	8	64.1		
	HC	77	1446.6	378.8	9	126.3		
		102	1164.2	252.8	9	84.3		
SG5 max (με)	LC	77	716.3	207.8	8	73.5	0.078	0.783
		102	508.6	160.1	8	56.6		
	HC	77	979.5	252.5	9	84.2		
		102	732.5	183.8	9	61.3		
Max Puck Velocity (m/s)	LC	77	21.2	2.1	8	0.8	0.718	0.404
		102	19.6	3.4	8	1.2		
	HC	77	24.2	2.7	9	0.9		
		102	24.1	2.0	9	0.7		
			Times					

			Calibre				
SG1 time to peak strain (ms)	LC	737.7	274.4	16	68.6	0.178	0.676
	HC	699.9	238.5	18	56.2		
SG2 time to peak strain (ms)	LC	741.0	275.6	16	68.9	0.218	0.644
	HC	699.1	238.3	18	56.2		
SG3 time to peak strain (ms)	LC	736.5	274.5	16	68.6	0.180	0.674
	HC	698.5	238.4	18	56.2		
SG4 time to peak strain (ms)	LC	735.3	273.7	16	68.4	0.175	0.678
	HC	697.9	238.3	18	56.2		
SG5 time to peak strain (ms)	LC	734.9	273.7	16	68.4	0.170	0.683
	HC	698.1	238.3	18	56.2		
SG1 avg load rate IC to peak (με/ms)	LC	0.4	0.2	16	0.0	5.254	0.029
	HC	0.5	0.2	18	0.0		
SG2 avg load rate IC to peak (με/ms)	LC	0.2	0.0	16	0.0	3.486	0.072
	HC	0.6	0.3	18	0.0		
SG3 avg load rate IC to peak (με/ms)	LC	0.2	0.1	16	0.0	4.287	0.047
	HC	0.3	0.2	18	0.0		
SG4 avg load rateIC to peak (με/ms)	LC	0.2	0.1	16	0.0	4.135	0.051
	HC	0.2	0.1	18	0.0		
SG5 avg load rate IC to peak (με/ms)	LC	0.1	0.1	16	0.0	2.374	0.134
	HC	0.2	0.1	18	0.0		
SG1 avg decay rate peak to PR (με/ms)	LC	-2.5	1.8	16	0.1	9.294	0.005
	HC	-4.9	2.9	18	0.2		
SG2 avg decay rate peak to PR (με/ms)	LC	-2.4	2.4	16	0.1	6.937	0.013
	HC	-4.8	3.0	18	0.2		
SG3 avg decay rate peak to PR (με/ms)	LC	-1.5	1.0	16	0.1	9.075	0.005
	HC	-2.9	1.8	18	0.1		
SG4 avg decay rate peak to PR (με/ms)	LC	-0.9	0.6	16	0.0	8.822	0.006
	HC	-1.9	1.1	18	0.1		
SG5 avg decay rate peak to PR (με/ms)	LC	-0.6	0.4	16	0.0	7.310	0.011
	HC	-1.2	0.7	18	0.0		
Blade-ice contact from IC-PC (ms)	LC	565.2	260.0	16	65.0	0.009	0.924
	HC	556.2	272.8	18	64.3		
Shot time from IC- PR (ms)	LC	827.7	268.6	16	67.2	0.001	0.978
	HC	824.7	321.5	18	75.8		
Blade-puck contact time from PC-PR (ms)	LC	262.4	81.5	16	20.4	0.052	0.820
	HC	268.5	67.4	18	15.9		
			Stick				
SG1 time to peak strain (ms)	77	738.6	279.7	17	67.8	0.177	0.677
	102	696.7	229.3	17	55.6		

SG2 time to peak strain (ms)	77		738.4	280.0	17	67.9	0.151	0.701
	102		699.2	230.7	17	56.0		
SG3 time to peak strain (ms)	77		737.3	280.2	17	67.9	0.176	0.678
	102		695.5	228.8	17	55.5		
SG4 time to peak strain (ms)	77		736.1	280.1	17	67.9	0.171	0.682
	102		694.9	227.9	17	55.3		
SG5 time to peak strain (ms)	77		736.2	280.2	17	68.0	0.174	0.679
	102		694.6	227.8	17	55.2		
SG1 avg load rate IC to peak (με/ms)	77		0.5	0.2	17	0.0	2.082	0.159
	102		0.4	0.2	17	0.0		
SG2 avg load rate IC to peak (με/ms)	77		0.5	0.2	17	0.0	3.811	0.060
	102		2.2	2.9	17	0.2		
SG3 avg load rate IC to peak (με/ms)	77		0.3	0.2	17	0.0	0.671	0.419
	102		0.3	0.1	17	0.0		
SG4 avg load rateIC to peak (με/ms)	77		0.2	0.1	17	0.0	0.442	0.511
	102		0.2	0.1	17	0.0		
SG5 avg load rate IC to peak (με/ms)	77		0.2	0.1	17	0.0	1.737	0.198
	102		0.1	0.1	17	0.0		
SG1 avg decay rate peak to PR (με/ms)	77		-4.7	3.1	17	0.2	5.127	0.031
	102		-2.9	1.8	17	0.1		
SG2 avg decay rate peak to PR (με/ms)	77		-4.6	3.0	17	0.2	4.278	0.047
	102		-2.8	3.0	17	0.2		
SG3 avg decay rate peak to PR (με/ms)	77		-2.7	1.8	17	0.1	3.841	0.059
	102		-1.8	1.2	17	0.1		
SG4 avg decay rate peak to PR (με/ms)	77		-1.7	1.2	17	0.1	3.400	0.075
	102		-1.1	0.9	17	0.1		
SG5 avg decay rate peak to PR (με/ms)	77		-1.1	0.7	17	0.0	4.989	0.033
	102		-0.7	0.5	17	0.0		
Blade-ice contact from IC-PC (ms)	77		575.8	283.8	17	68.8	0.080	0.779
	102		545.2	248.0	17	60.1		
Shot time from IC- PR (ms)	77		841.1	332.0	17	80.5	0.062	0.805
	102		811.2	258.4	17	62.7		
Blade-puck contact time from PC-PR (ms)	77		265.3	74.4	17	18.0	0.000	0.988
	102		266.0	74.4	17	18.0		
Calibre*Stick								
SG1 time to peak strain (ms)	LC	77	720.5	296.9	8	105.0	0.649	0.427
		102	754.9	269.3	8	95.2		
	HC	77	754.8	280.6	9	93.5		
		102	645.0	187.9	9	62.6		
SG2 time to peak strain (ms)	LC	77	721.0	297.8	8	105.3	0.696	0.411

		102	761.0	270.3	8	95.6		
	HC	77	753.9	280.3	9	93.4		
		102	644.3	188.0	9	62.7		
SG3 time to peak strain (ms)	LC	77	719.3	298.1	8	105.4	0.646	0.428
		102	753.7	268.2	8	94.8		
	HC	77	753.2	280.4	9	93.5		
		102	643.7	188.1	9	62.7		
SG4 time to peak strain (ms)	LC	77	717.8	298.0	8	105.4	0.649	0.427
		102	752.8	266.4	8	94.2		
	HC	77	752.4	280.3	9	93.4		
		102	643.4	188.1	9	62.7		
SG5 time to peak strain (ms)	LC	77	717.7	298.2	8	105.4	0.645	0.428
		102	752.2	266.4	8	94.2		
	HC	77	752.6	280.3	9	93.4		
		102	643.5	188.3	9	62.8		
SG1 avg load rate IC to peak (με/ms)	LC	77	0.4	0.2	8	0.0	0.007	0.935
		102	0.4	0.1	8	0.0		
	HC	77	0.6	0.2	9	0.0		
		102	0.5	0.2	9	0.0		
SG2 avg load rate IC to peak (με/ms)	LC	77	0.5	0.2	8	0.0	3.751	0.062
		102	0.4	0.5	8	0.1		
	HC	77	0.6	0.3	9	0.0		
		102	0.6	0.3	9	0.0		
SG3 avg load rate IC to peak (με/ms)	LC	77	-1.9	1.0	8	0.1	0.012	0.912
		102	-1.0	0.8	8	0.1		
	HC	77	-3.3	2.1	9	0.2		
		102	-2.4	1.1	9	0.1		
SG4 avg load rateIC to peak (με/ms)	LC	77	-1.2	0.6	8	0.1	0.001	0.973
		102	-0.7	0.5	8	0.1		
	HC	77	-2.2	1.4	9	0.2		
		102	-1.6	0.8	9	0.1		
SG5 avg load rate IC to peak (με/ms)	LC	77	-0.8	0.4	8	0.1	0.067	0.798
		102	-0.4	0.3	8	0.0		
	HC	77	-1.4	0.9	9	0.1		
		102	-0.9	0.5	9	0.1		
SG1 avg decay rate peak to PR (με/ms)	LC	77	-3.3	1.8	8	0.2	0.061	0.807
		102	-1.7	1.4	8	0.2		
	HC	77	-5.9	3.6	9	0.4		
		102	-3.9	1.5	9	0.2		
SG2 avg decay rate peak to PR (με/ms)	LC	77	-3.8	2.5	8	0.3	0.816	0.374
		102	-1.1	1.4	8	0.2		

	HC	77	-5.3	3.4	9	0.4		
		102	-4.3	2.6	9	0.3		
SG3 avg decay rate peak to PR (με/ms)	LC	77	0.3	0.1	8	0.0	0.054	0.817
		102	0.2	0.1	8	0.0		
	HC	77	0.3	0.2	9	0.0		
		102	0.3	0.1	9	0.0		
SG4 avg decay rate peak to PR (με/ms)	LC	77	0.2	0.1	8	0.0	0.019	0.892
		102	0.2	0.1	8	0.0		
	HC	77	0.2	0.1	9	0.0		
		102	0.2	0.1	9	0.0		
SG5 avg decay rate peak to PR (με/ms)	LC	77	0.1	0.1	8	0.0	0.008	0.929
		102	0.1	0.1	8	0.0		
	HC	77	0.2	0.1	9	0.0		
		102	0.1	0.1	9	0.0		
Blade-ice contact from IC-PC (ms)	LC	77	544.0	219.0	8	77.4	0.543	0.467
		102	586.5	309.6	8	109.5		
	HC	77	604.1	342.3	9	114.1		
		102	508.4	189.4	9	63.1		
Shot time from IC- PR (ms)	LC	77	809.0	263.5	8	93.1	0.367	0.549
		102	846.4	290.6	8	102.7		
	HC	77	869.6	397.2	9	132.4		
		102	779.9	239.4	9	79.8		
Blade-puck contact time from PC-PR (ms)	LC	77	265.0	88.6	8	31.3	0.044	0.835
		102	259.9	79.7	8	28.2		
	HC	77	265.5	64.8	9	21.6		
		102	271.4	73.7	9	24.6		