THE CONTRIBUTION OF SKATE BLADE PROPERTIES TO SKATING SPEED

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Abstract

The purpose of the study was to investigate the relative contribution of skate blade properties to on-ice skating speed. Thirty-two male ice hockey players (mean age = 19±2.65 yrs.) representing the Ontario Minor Hockey Association (OMHA; Midget AAA and Junior), Canadian Inter University Sport (CIS: Varsity), Ontario hockey league (OHL) and East Coast Hockey League (ECHL), and the playing positions of forwards (n=18) and defense (n=14) were recruited to participate. Skate related equipment worn by the players for the purpose of the research was documented and revealed that 80% of the players wore Bauer skates, Tuuk blade holders and LS2 skate blades. Subjects completed a battery of eight on-ice skating drills used to measure and compare two aspects of skating speed; acceleration [T1(s)] and total time to complete each drill [TT(s)] while skating on three skate blade conditions. The drills represented skills used in the game of hockey, both in isolation (e.g., forward skating, backward skating, stops and starts, and cornering) and in sequence to simulate the combination of skills used in a shift of game play. The three blade conditions consisted of (i) baseline, represented by the blades worn by the player throughout their current season of play; (ii) experimental blades (EB), represented by brand name experimental blades with manufacturers radius of contour and a standardized radius of hollow; and (iii) customized experimental blades (CEB), represented by the same brand name experimental blades sharpened to the players' preference as identified in the baseline condition. No significant differences were found in acceleration time [T1(s)] or total time to complete [TT(s)] the isolated drills across blade conditions; however significant differences were revealed in both T1(s) and TT(s) measured during the execution of the sequenced drill across blade conditions. A

Bonferroni post hoc test revealed that players skated significantly faster when skating on the CEB condition compared to the baseline condition ($p \leq .05$). A questionnaire assessing subjects perceived comfort, confidence and effort expended while skating on the experimental blades revealed that players were significantly more comfortable when skating on the CEB versus the EB condition ($p \leq .05$). Outcomes of the study provide evidence to suggest that the experimental skate blades customized with the players preferred blade sharpening characteristics results in faster skating speed in a combination drill representing skills performed in gameplay.

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Table of Contents

List of Tables

List of Figures

Abbreviations

ROH: Radius of Hollow (cm [in])

ROC: Radius of Contour (cm [in])

B: Baseline Condition

EB: Experimental Blade Condition

CEB: Customized Experimental Blade Condition

T1: Acceleration Time (s)

TT: Total Time to complete (s)

RFID: Radio Frequency Identification

RPE: Rate of Perceived Exertion

CHAPTER I: INTRODUCTION

Is hockey hard? I don't know, you tell me. We need to have the strength and power of a football player, the stamina of a marathon runner, and the concentration of a brain surgeon. But we need to put all this together while moving at high speeds on a cold and slippery surface while 5 other guys use clubs to try and kill us, oh yeah did I mention that this whole time we're standing on blades 1/8 of an inch thin? (Brendan Shanahan, 2010).

On-ice performance in the sport of ice hockey is dependent upon a player's ability to harness physical fitness, technical skill and mental toughness through effective equipment design. The sport equipment industry claims that the evolution of equipment has been driven by sport-specific demands leading to an understanding that equipment contributes significantly to game play and performance. To date, research addressing the contribution of equipment to performance suggests a relationship may exist (Froes, 1997; Jenkins, 2003; Subic, 2007) however fails to provide a metric or specifically address the question, what is the added value of select equipment items to sport performance?

In theory sport-specific performance models have been developed to identify contributing factors to performance success. MacDougall, Wenger and Green (1991) theorized that genetic endowment is the foundation for athletic success, isolated studies have suggested that training physiological (Duthie, 2006: Zuozienė & Poderys, 2012), technical (Clemente, Martins & Mendes, 2015) and psychological (Mahoney, Gabriel & Perkins, 1987) variables are required for an athlete to reach their genetic potential, regardless of the specific sport participation. Although the relative contribution of each variable may vary between athletes within a sport and/or across different sports, the blend is integral for athletic success. That said, these studies have failed to include equipment as a contributing factor to sport success. This shortfall has lead to more recent articles that have investigated the effects of equipment on performance, revealing that in the broader sporting industry advances in design and material properties of sporting equipment have resulted in enhanced performance (Froes, 1997; Shorten, 2000; Subic, 2007). More specifically, research conducted on advances in hockey equipment has revealed significant performance advances (Robert-Lachaine, Turcotte, Dixon & Pearsall, 2012; Villaseñor, Turcotte & Pearsall, 2006).

Skate blades are commonly referred to as the "bottom line" meaning that, the interaction between skate blades and the ice surface is fundamental to a player's ability to skate. Research addressing the contribution of skate blades to on-ice sport has been somewhat compartmentalized, suggesting that isolated aspects such as design (Federolf, Mills & Nigg 2008; Federlof & Nigg, 2012), material properties (Abkowitz, Abkowitz, Fisher & Schwartz, 2004) and sharpening (Federlof & Redmond, 2010; Donnelly, 2010; McKenzie & Lockwood, 2012; Winchester & Lockwood, 2006), have the potential to independently affect skating performance. More specifically, skate blade design has the ability to decrease friction resulting in faster skating speeds (Federlof et al, 2008; Federlof & Nigg, 2012); changes to the material properties of skate blades have resulted in greater impact resistance, edge retention and a decrease in blade weight (Albowitz et al., 2004); skate sharpening research has indicated that changes in blade contours and hollows have the ability to decrease stopping distances, increase stride length and enhance skating efficiency (Federlof & Redmond, 2010; Gagnon & Dore, 1983; Lockwood & McKenzie, 2012, Winchester & Lockwood, 2006). Collectively, this body of knowledge suggests that skate blades are fundamental to skating and have the potential to contribute significantly to on-ice skating performance.

This study is an extension of an industrial collaboration research project aimed to address the contribution of skate blades to skating performance. A preliminary study investigated the material properties of the experimental skate blades and revealed that they have an increased surface hardness when compared to stainless steel that is commonly used in the hockey industry. Expanding upon this knowledge, a comprehensive analysis of the relative contribution of the experimental skate blades with customized skate sharpening characteristics was proposed. Therefore, the purpose of the study was to investigate the relative contribution of skate blades to on-ice skating speed.

CHAPTER II: REVIEW OF LITERATURE

Sport-specific performance models have been developed to investigate the contributing factors to athletic success. Many models often focus on physiological, biomechanical and socio-psychological factors. However within context of conventional sport equipment and apparel, research investigating the contribution of athletic performance supports the notion that equipment contributes to athletic success (Froes, 1997; Jenkins, 2003; Shorten, 2000; Subic, 2007). Therefore it could be suggested that equipment facilitates the transfer of athletic preparedness to sport performance and should be quantified to determine the effects of equipment on sport performance.

2.0 Contribution of Equipment to Athletic Performance

The design, material properties and maintenance of sporting equipment requires the application of multiple disciplines including biomechanics, material science and engineering to develop equipment that enables athletes to harness their physical fitness and technical skill translating to sport performance. Specific to the sport of ice hockey, the evolution of equipment has primarily served two purposes; (i) to prevent injury, and (ii) to optimize performance. Research conducted on hockey equipment has primarily focused on three categories: (i) protective gear consisting of helmets, facial shields, shoulder pads, shin pads, elbow pads, pants and gloves; (ii) hockey sticks and (iii) skates consisting of the skate boot, blade holder and skate blades.

Protective gear was originally designed to keep players warm, however due to the increased size of players, physicality and speed of the game, protective gear has evolved into ‘coat of armor’ that primarily protects against injury. Beyond protection, hockey equipment has been designed deliver and protect. Impact and body movement data have driven the evolution of hockey equipment, design and material property changes have advanced pads, pants and gloves, creating equipment with rigid plastics attached to malleable and synthetic materials that has increased impact resistance while allowing the natural motion of joints (Watkins, 2009). Research investigating the geometry, material properties of helmet shells and linings has suggested that current technology increases impact absorption qualities, thus increasing protection of players' heads (Gimble & Hoshizaki, 2008; Spyrou, Pearsall & Hoshizaki, 2001). Further to immediate protection during game play, Pearsall & Dowler (2008) conducted a longitudinal study investigating the shelf life of five brands of hockey helmets and indicated that helmets maintained their impact attenuation over a six-year period. The use of full and half facial shields has suggested that players who wear a facial shield endure less head, neck facial injuries and return to play faster after suffering a concussion (Asplund, Bettcher & Borchers, 2009; Lemair & Pearsall, 2007). Aftermarket protective gear, such as shot blockers added to skates (Shot Blockers, 2015; Skate Fenders, 2015) and cut resistant socks (Base 360, 2015; Gladiator Socks, 2015; Swiftwick, 2015; Tuff n Lite Hockey, 2015) have been developed to further protect players from pucks and lacerations caused by skates.

Hockey sticks have evolved from wood sticks with straight blades to composite blends with a wide selection of flexes, curves and lie of blades. Advancements in hockey sticks have been primarily performance driven, namely, to increase shot velocity. Manufacturers offer composite sticks that give players options to modify sticks to meet their preferences including choices in regards to flex, weight, flex point, grip, blade shape/lie and strength (Marino, 1998; Worobets, Fairbain, & Stefanyshyn, 2006; Wu et al., 2003). Research investigating the effects of shaft stiffness on shot performance has revealed that stick flex alone does not affect shot velocity, however when analyzed with shot biomechanics (Worobets, Fairbain, & Stefanyshyn, 2006; Wu et al., 2003), player caliber (Hannon, Michau-Paquette, Pearsal & Turcotte, 2011; Villaseñor, Turcotte & Pearsall, 2006; Wu et al, 2003), gender and strength (Wu et al., 2003) as covariates, significant differences in shot velocity were revealed. The above research suggests that shot velocity is dependent upon stick flex and a player's ability to manipulate the flex of a hockey stick. Player's perceived feel of a hockey stick is a primary factor when choosing a stick, composite sticks allow players to have some perception of where the puck is on their stick thus increasing their comfort while using a composite stick compared to a wood stick (Anderson, 2008). Thus previous research suggests that players prefer the feel of composite sticks compared to wood sticks and are able to produce increased shot velocities.

The hockey skate consists of three main components: skate boots, blade holders and blades. Skate boots have been designed to protect a player's foot and provide lateral support (Ali Hadi, 2001), but have also been developed to allow the natural motion of the foot and ankle (Humble & Smith, 2010). Interestingly, there is debate with regard to the lateral support and protection that are required in hockey skates. The stiffness of current skates can limit the amount of ankle range of motion (ROM) permitted, this lack of ROM has been shown to be detrimental to skating performance and contribute to undue fatigue (Ali Baig 2011; Hancock, 1999; Humble & Smith, 2010). Research exploring design modifications to the specific components of skate boots, such as elevated lacing patterns and increased tongue flexibility have been implemented to address ROM with the intent of improving plantar and dorsiflexion (Fortier, Turcotte & Pearsall, 2014; Robert-

Lachaine, Turcotte, Dixon & Pearsall, 2012). The increase in plantarflexion permitted by modified skate boots has allowed players to increase blade ice contact time during the push-off phase of a stride resulting in a delay of undue fatigue and an increase force production (Robert-Lachaine, Turcotte, Dixon & Pearsall, 2012). Although players are able to increase ROM and force production with a modified skate boot, on-ice results are inconclusive, when skating on modified skates players were unable to significantly improve on-ice performance measures when compared to conventional skates (Fortier, Turcotte & Pearsall, 2014; Robert-Lachaine, Turcotte, Dixon, Pearsall, 2012). Conversely, research conducted on a novel aftermarket product developed to increase ROM and a modified skate boot with increased tendon guard flexibility have suggested significant increases in dorsi-plantar ROM, skating stride length and an on-ice measure of two-step acceleration speed (Lockwood et al., 2013; Lockwood et al., 2014) and a trend towards increased torque and mean work per stroke when compared to a conventional skate (Pearsall, Paquette, Baig, Albrecht & Turcotte, 2012).

The material properties of the skate boots and related components have evolved from traditional leather construction to stiffer, lighter synthetic materials resulting in skate boots that optimize durability, comfort, fit, support and protection (Humble & Smith, 2010; Pearsall & Turcotte, 2007). Blade holders are an essential component of the skate complex as they secure the blade to the boot. The original construction of blade holders consisted of a single piece of tubular metal blade riveted to the skate boot. Baikie (1978) patented the TUUK blade holder that addressed the ease of use issue and has become a leader in hockey equipment industry. The company's original design was an elongated blade that was attached to a plastic blade holder using nuts and bolts allowing players to change their skate blades without changing the entire blade holder (Baikie, 1978). Further modifications in the TUUK patent have results in quick release button that a permits blades to be changed quickly without the use of tools (Baikie, 1997).

Skate blades are referred to as the bottom line to a player's ability to transfer physical fitness and technical skill to their skating abilities. When skate blades were first introduced, individuals would strap bones to their boots; modern skate blades have evolved into curved metal blades securely attached to a hockey skate boot. The geometry of skate blades can be defined by blade width, length and height. Blade width can be defined as the distance between the two sides of the blade, depending on manufacturer blade width can vary from 2.29mm to 3.05mm. Blade length is proportional to boot size and is defined by the distance from the toe to the heel of the blade (Broadbent, 1985). Blade height is measured as the vertical distance of the blade, new skate blades vary across manufacturer ranging from 17.41mm to 21.32mm and will decrease as they are sharpened. Stainless steel has the material properties that give blades strength, durability and malleability making this material common in the industry of hockey blades (Donnelly, 2010; Horkemier, 2007).

Friction is a function of surface area and material properties, therefore it could be suggested that friction is as a major contributor of speed for sports played on ice. In the sport of speed skating thin skate blades have been viewed as ideal for speed, however hockey skate blades need to be thick enough to handle the various demands of the game (Federlof et al., 2008). The geometry of skate blades has not been significantly altered since the innovation of a curved skate blade attached to Tuuk blade holders. Federolf and Nigg (2012) studied a flared skate blade design that was wider than conventional blades, results of the study reported increased on-ice performance in skating speed, acceleration and a glide turn test. Innovations such as heat treatments and coating blades with diamond and titanium composites have changed the material properties and created after-market skate blades that are lighter, have an increased surface hardness, enhanced wear resistance and impact resistance compared to stainless steel (Abkowitz et al., 2004; Donnelly, 2010). Manufactures claim that an increased surface hardness reduces the coefficient of friction and allows players to skate faster (Step Steel, 2014), however on-ice performance research has yet to be conducted to support company claims.

Skate blades are maintained through a process of sharpening. In theory, skate sharpening has the potential to change or alter the dimensions of the skate blade. Historically, the skate sharpening process consisted of hand-honing the blade by running a long sharpening stone along the length of the blade to remove burs and rust that had formed (Brown, 1959). The development of skate sharpening machines and related technology has led to the practice of skate sharpening becoming an automated process (Wissota, 2014). The novel machines also permit sharpening technicians to alter the geometry of the blade such as the radius of contour (ROC), radius of hollow (ROH), pitch and edge levelness, to accommodate for player preference. ROC is defined as the longitudinal curvature of the skate blade and determines the amount of blade in contact with the ice during a skating stride (Broadbent, 1988). A longer radius creates more blade-ice contact and as such, allows a player to generate more speed and have more stability. In comparison, a shorter radius permits less blade contact and facilitates a tighter turning radius. ROH is defined as the concave groove along the length of the blade creating a bite angle otherwise known as the angle of penetration, permitting the blades to grip into the ice (Broadbent, 1983; 1998). Broadbent (1988) theorized that a shallower ROH facilitates glide and increases skating velocity, while a deeper ROH improves more agility related maneuvers, such as stops, starts, pivots and turns. Pitch is defined as the apex of a skate blade; moving the apex changes the balance point of the blade and can be adjusted to move a player's center of mass (COM). If moved forward of blade center, a player's COM would be shifted back and if moved backward from blade center, COM would be shifted forward (Broadbent, 1988). Edge levelness can be defined as having the lateral and medial edges of skate blades at the same height relative to one another. It can be viewed as a quality control measure for sharpening, rather than a characteristic a sharpening technician will alter (Broadbent, 1985). Theoretically, unleveled edges are suggested to negatively affect on-ice skating performance and potentially increase injury (Lockwood & Frost, 2009).

Blade-ice interaction or the effect of skating sharpening on skating performance has been investigated through isolated studies, namely, the effects of ROH (Federlof & Redmond, 2010; Winchester & Lockwood, 2006) and ROC (Lockwood & McKenzie, 2012) on skating performance. Federlof and Redmond (2010) examined changes to ROH in relation to skating speed and found that there were subject specific differences although there were no significant changes in group performance on blade hollows between 9.53-22.23mm. Additional ROH investigations using both mechanical and human models have reported that adjusting ROH has the potential to create a longer stride length, improve stopping time and a decrease in stopping distance (Gagnon & Dore, 1983; Winchester & Lockwood, 2006). Recent studies investigating the effect of ROC on skating performance have suggested that ROC is significantly correlated to a player's body weight, indicating that players can increase skating efficiency on an optimized ROC compared to the contours of players' choice (Lockwood & McKenzie, 2012). It is suggested that heavier players should skate on a longer ROC and lighter players should skate on a shorter ROC to produce faster skating times (Lockwood & McKenzie, 2012).

Skate blade research has suggested that isolated aspects of skate blades have the ability to individually affect on-ice performance. However there is limited research that addresses a more comprehensive approach that quantifies the relative contribution of combined effect of design, material properties and maintenance of skate blades to on-ice performance.

2.1 On-Ice Performance Assessments

Traditionally on-ice performance assessments have been developed to assess how a player harnesses physiological fitness through technical skill and equipment design using sport-specific movements. On-ice performance is often assessed using drills that represent desired skating skills such as, sprint speed, agility moves, stopping and a combination of puck skills paired with skating abilities using time as a metric. A recent study conducted by Nightingale (2013) investigated the reliability and validity of an on-ice agility test, the author reported a high test-retest reliability for the study's on-ice testing protocol providing empirical evidence to support the use of on-ice performance tests. The Repeat Ice Skating Test (RIST), Reed Repeat Spring Skate (RSS) and Sargent Anaerobic Skate (SAS40) are examples of sport-specific assessments designed to measure a player's physiological fitness, namely, anaerobic power and anaerobic capacity in a field like environment. The RIST and RSS assessments correlate positively to anaerobic measures calculated on the Wingate anaerobic tests (Power, Faught, Przysucha, McPherson & Montelpare, 2012; Reed et al., 1979). The Faught Aerobic Skating Test (FAST) is an on-ice assessment created to predict aerobic power and has shown positive correlations to an aerobic power treadmill test utilizing a modified Bruce incremental treadmill protocol (Petrella, Montelpare, Nystrom, Plyley & Faught, 2007). Individual studies have developed on-ice assessments using players as their own controls with standardized distances and movement requirements designed to assess specific skills and the effects of equipment on performance (Federlof & Redmond, 2010; Lockwood & McKenzie, 2012; Rocznioka et al., 2012; Winchester & Lockwood, 2006). Alternatively researchers have developed used strain force gauges (Fortier, Turcotte & Pearsall, 2014; Robert-Lachaine, Turcotte, Dixon & Pearsall, 2012; Stidwill, Turcotte, Dixon & Pearsall, 2009) to biomechanically analyze and generate a metric of force production during a skating stride.

In summary, research conducted on component specific equipment pieces has investigated the effects of equipment on on-ice performance. Evidence of the isolated effects of blade design, material properties and blade maintenance on skating performance suggested that individual components have the potential to affect skating speed. To the knowledge of this researcher, there are currently no studies that have investigated the combined effect of design, material properties and blade maintenance and their effects on on-ice performance, namely skating speed.

Aftermarket skate blades have been developed with the aim of addressing blades that are resistant to impact, have increased edge retention and transfer athlete preparedness to game play. An aftermarket skate blade brand has designed a skate blade that is heat-treated and coated creating an increased surface hardness, which in theory reduces the coefficient of friction. A study investigating the combined effect of a blade with an increased surface hardness in combination with optimized skate sharpening has yet to be investigated.

2.2 Purpose

The purpose of the study was to investigate the relative contribution of skate blades to on-ice skating speed. It will be assumed that physiological fitness, technical skill, equipment and mental toughness will be held constant, as players will be their own control. To our knowledge, players were injury free and in mid-season playing condition during the testing protocol.

The primary null hypothesis states there is no significant difference in skating speed (SP) across blade conditions.

$$H_1 = SP_{BASELINE} = SP_{EXPERIMENTAL\ BLADES} = SP_{CUSTOMIZED\ EXPERIMENTAL\ BLADES}$$

2.3 Significance of the Study

This study has the potential to provide valuable insight into the contribution of equipment, namely skate blades, to on-ice skating speed. It may also encourage equipment manufacturers to continue to make design and material property changes and validate performance advantages created by equipment evolution.

2.4 Limitations

a) On-ice testing was limited by time; regularly scheduled team practices were used for testing sessions and coaches would only commit to three practices.

b) Due to limited resources, each subject was supplied with only one set of skate blades and therefore, randomization of trials was limited. The second condition could not precede the third condition.

c) The results cannot be generalized to the population of female elite hockey players due to a gender bias in the subject cohort.

CHAPTER III: METHODS

3.1 Study Design

A quasi-experimental design was implemented to investigate the relative contribution of skate blades to on-ice skating speed. A battery of on-ice skating drills in three blade related conditions was completed. Only one set of experimental skate blades were provided to each subject. The experimental skate blades were visually different from the baseline condition therefore subjects could not be blinded. However, subjects were blinded to skate sharpening characteristics during the experimental blade conditions. Two selected interval times measured in seconds (s), were selected to investigate the affects of skate blade conditions on on-ice skating speed. Acceleration Time (T1) or "quick off the line" movement was represented by subject's two-step acceleration time measured from the starting mark to the first timing gate located a distance of 2 feet away. Total Time (TT) was represented by time to complete drill the skating drills, total distance was drill dependent. Subjects were required to wear full protective equipment and use their hockey sticks. Skate boots and blades holders were consistent across all conditions. Condition 1, referred to as baseline (B) was completed on the subject's current skate blades sharpened to their individual specifications. Condition 2, referred to as the experimental blade (EB) was completed on experimental skate blades sharpened with a standardized ROC and ROH. Condition 3, referred to customized experimental blade (CEB) was completed on the same pair of experimental skate blades, sharpened to subject's individual sharpening characteristics. During conditions 2 and 3, experimental blades were inserted and sharpened by one skilled technician. Multiple analyses of variance were used to investigate the effect of skate blade conditions on on-ice skating speed.

3.2 Subjects

Thirty-two male, competitive level ice hockey players ranging in age from 16-25 years were recruited to participate. A power analysis using Cohen's d was conducted (α=.05, β=0.2) with a moderate effect size (0.7) to calculate a sample size of 32 subjects. Recruitment was limited to subjects currently competing, playing in the positions of forward and defense and injury free. Subject's current skate information and sharpening characteristics were recorded (Table 1). The study received ethical approval from the Brock University Research Ethics Board under an existing proposal (FILE NUMBER) and participants provided informed consent.

3.4 On-Ice Assessment Protocol

A battery of eight on-ice skating drills representing skills used during aspects of game play (e.g., forwards, backwards, agility, stops/starts, crossovers and tight turns), measuring Acceleration Time (T1) and Total Time (TT) to complete drills (s) was implemented. Subjects wore full protective gear that remained consistent during testing sessions. Skating drills were completed on three blade related conditions: baseline (B), experimental blades (EB) and customized experimental blades (CEB). A standardized fifteen minute familiarization and warm up period was allotted prior to all testing conditions to ensure players became accustomed to ice conditions, the experimental blades and sharpening characteristics. The warm up included sport-specific on-ice skating drills (i.e. forwards/backwards skating, tight turns, shuffles, cross-overs and pivots) performed at increasing intensity. The order of skating drills remained constant across all conditions. On-ice assessments were performed on separate days with adequate rest between testing sessions. For the purpose of this study, all experimental blades were provided by RZR skate blades, installed and sharpened by the researchers. It was assumed that physical fitness, technical skill, equipment and mental toughness were held constant, as players were their own control. To the knowledge of the researcher, players reported they were injury free and in mid-season playing condition during the testing protocol.

Two select aspects of skating speed, Time 1 (T1; s) representing acceleration or "quick off the line" movement and Total Time (TT; s) representing time to complete drills were measured using a Swift™ timing light system (Swift Performance Equipment, Carole Park, QLD). To facilitate ease and confidentiality of data collection, subjects were fitted with a Radio Frequency Identification (RFID) tag. Each RFID tag is a small wireless device that individually identifies subjects and permits the transfer of time (recorded data) to computer. Verbal encouragement was provided to all players to encourage maximal effort.

A detailed protocol for each condition is as follows:

<u>Condition #1 Baseline</u>: Subjects completed the battery of on-ice drills skating on their current skate blades sharpened to their individual specifications. Skate blade brand, size and current skate blade sharpening characteristics including radius of contour (ROC), radius of hollow (ROH) and edge levelness were measured and recorded. ROC was measured using Blademaster Contour Radius Bars (Guspro Inc., Chatham, ON). ROH was measured using a hollow depth indicator at three distinct locations: toe, center and

heel of the blade (Edge Specialties Inc., Alexandria, MN). Edge levelness was determined using a Quick Square level (Maximum Edge™, Windsor, ON).

Condition #2 Experimental Blade: Subjects completed the battery of on-ice drills skating on an experimental pair of skate blades. ROC and ROH of the experimental blades were standardized to the manufacturer's specifications. ROH was applied to the grinding stone using a Blademaster Radius Arm Dresser (Guspro Inc,. Chatham, ON) and verified using a hollow depth indicator at three distinct locations: toe, center and heel of the blade (Edge Specialties Inc., Alexandria, MN). Edge levelness was verified using a Quick Square level (Maximum Edge™, Windsor, ON); a tolerance of 1/1000 inch was set.

Condition #3 Customized Experimental Blade: Subjects completed the battery of on-ice drills skating on the same pair of experimental blades as the EB condition, however sharpened to subjects' preferred sharpening characteristics as recorded from the Baseline condition. ROC was applied to the blades using a Blademaster Single Point Custom Contouring System (Guspro Inc., Chatham, ON). The accuracy of the ROC was verified using Blademaster Contour Radius Bars (Guspro Inc., Chatham, ON). ROH was applied to the grinding stone using a Blademaster Radius Arm Dresser (Guspro Inc,. Chatham, ON) and verified using a hollow depth indicator at three distinct locations: toe, center and heel of the blade (Edge Specialties Inc., Alexandria, MN). Edge levelness was verified using a Quick Square level (Maximum Edge™, Windsor, ON); a tolerance of 1/1000 inch was set. One skilled technician sharpened all blades prior to EB and CEB conditions to ensure consistency and quality of sharpening.

Upon completion of the on-ice battery of drills in the EB and CEB conditions, subject feedback was solicited using a questionnaire investigating perceived comfort (e.g., control and confidence) and perceived performance (e.g., speed, glide and grip) (Appendix A). All responses were rated on a Likert scale (1 to 5) and compared to the baseline condition. A final question rating subjects' perceived exertion was rated on a scale from 1 to 10 and compared across conditions. Individual responses were tallied to create a total score for each subject.

3.5 Statistical Analysis

Data was analyzed using the Statistical Package for the Social Sciences (SPSS) software, version 20 (IBM, Chicago, IL). Descriptive statistics, including mean (M) and standard deviation (SD) were calculated for all variables. A within subject Repeated Measures Analysis of Variance (ANOVA) was conducted to determine if significant differences existed between T1 across three blade related conditions [baseline (B), experimental blades (EB), customized experimental blades (CEB)]. A within subject repeated measures ANOVA was conducted to determine if significant differences exist between TT across three blade related conditions. A within subject repeated measures ANOVA was conducted to determine if significant differences exist between the T1 composition score of the seven isolated skating drills across three blade related conditions. A within subject repeated measures ANOVA was conducted to determine if significant differences exist between the TT composition score of seven isolated skating drills by three blade related conditions. A within subject repeated measures ANOVA was conducted to determine if significant differences exist between T1 of the combination drill by three blade related conditions. A within subject repeated measures ANOVA was conducted to determine if significant differences exist between TT of the combination drill by three blade related conditions. If significant differences were found, a *post-hoc*

Bonferroni significance test was performed to determine where the difference between the blade conditions by drill was located. A Kruskal-Wallis Test was performed to determine if there are significant differences between total scores on the subject questionnaire. An alpha level of $p \leq .05$ was set for all statistical analyses.

CHAPTER IV: RESULTS

4.1 Subject Descriptives

Fifty-four male hockey players were originally recruited to participate in the study, however due to players being traded and injured, 32 subjects completed the study (mean age of 19±2.65 yrs.). Subjects represented the playing positions of forwards (n=18) and defense (n=14) and the shooting directions of left (n=21) and right (n=11). The level of play or caliber of the players ranged from Midget AAA (n=11), Junior (n=12), University (n=8) and East Coast Hockey League (ECHL) (n=1). Skate related equipment was documented and revealed that 80% of the players wore Bauer skates, Tuuk blade holders and LS2 skate blades.

Skate blade characteristics including radius of contour (ROC; m[ft]), radius of hollow (ROH; cm[in]), pitch (cm[in]) and edge levelness (cm[in]) were measured and recorded for each subject at baseline (Table 1). The sharpening characteristics measured at baseline represented the subjects' current preferences. Eighty-one percent of the subjects were skating on a single contour, meaning that the ROC is comprised of one radius along the length of the blade. Single contours ranged from 2.13m (7ft) to 3.35m (11ft). The most frequent single contour (59%) was 2.74m (9ft). Nine percent of subjects were skating on a ROC equal to or less than 2.44m (8ft) and thirteen percent of subjects were skating on a ROC equal to or greater than 3.05m (10ft). Nineteen percent of subjects were skating on a double contour, meaning that the length of the blade had two radii. Typically, a double contour consists of a shorter radius forward of blade center and a longer radius backwards of blade center. All double contours measured were 2.74m (9ft) forward of blade center and 3.05m (10ft) backwards of blade center.

Data collected on ROH revealed that all subjects (100%) were skating on a conventional concave hollow as opposed to a non-traditional hollow. Radius of hollow measurements ranged from 0.95cm (3/8in) to 2.22cm (7/8in). The most frequent ROH used by the subjects (59%) was a 1.27cm (1/2in) hollow. Thirty-one percent of the cohort was skating on a ROH that was equal to or greater than 1.59cm (5/8in). The remaining ten percent of the subjects were skating on hollows less than or equal to 0.95 cm (3/8in). Pitch measurements revealed that 100% of the players were skating on a neutral pitch at the time of the study. Blade levelness was measured as a quality control for skate sharpening. Industry standard for edge levelness is a measurement less than 1/1000 of an inch, anything greater than 1/1000 of an inch was considered an unleveled edge in the study. These data revealed that forty-one percent of subjects' skate blades had leveled edges versus fifty-nine percent of subjects' skate blades that had unlevelled edges.

4.2 Statistical Analysis

A series of within subject Repeated Measures Analysis of Variance (ANOVA) were conducted to assess the effect of blade condition on skating speed. Acceleration defined as time 1 (T1) by blade condition (baseline (B), experimental blades (EB) and customized experimental blades (CEB)) measured during the seven on-ice skating drills (forwards, backwards, agility, stops and starts and cross overs) revealed no significant differences across blade conditions. Skating speed defined as Total Time (TT) to complete drills across blade condition measured during the seven on-ice skating drills revealed no significant differences across blade conditions.

A composition score across the seven on-ice skating drills for T1 and a composition score across seven on-ice skating drills for TT were calculated. The composition scores were calculated by tallying all T1 and TT times for each of the seven on-ice skating drills. Acceleration (T1) composite score by blade condition revealed no significant differences across blade conditions. Total time (TT) composite score by blade condition revealed no significant differences across blade conditions.

The combination drill represented skating skills in sequence as often performed during a shift of game play. Specifically, players were required to perform four isolated skating skills in sequence. Significant differences in acceleration (T1) across blade condition for the combination drill were revealed (Figure 3). A Mauchly's test of sphericity revealed that the assumption of sphericity was not supported for T1. The Greenhouse-Gessier correction was used and revealed a significant difference ($F[1.541, 47.762]=5.237$, $p<0.014$). A pairwise comparison using a Bonferroni correction revealed that players skating on the CEB condition were significantly faster than skating on the B condition ($p<0.001$), meaning that players were able to produce a faster "quick off the line" movement in the customized experimental blades.

Significant differences in total time (TT) to complete the combination drill across blade conditions were revealed (Figure 4). A Mauchly's test of sphericity revealed that the assumption of sphericity was supported and a significant difference ($F[1.541, 47.762]=5.237$, $p<0.014$) was found. A pairwise comparison using a Bonferroni correction revealed the CEB condition was significantly faster than the B condition ($p<0.029$), meaning that players were able to produce faster skating times in the customized experimental blades.

4.3 Player Perception Questionnaire Analysis

An eight-question pen and paper player questionnaire was completed after the EB and CEB conditions. The questionnaire included 7 questions investigating players' likes, dislikes, perceptions and confidence while skating on the experimental skate blades and one question rating players' level of perceived exertion during the testing session. The responses to the player perception questions were tallied to create a group composite score. A Kruskal-Wallis analysis was performed to investigate significant differences in questionnaire responses across blade conditions. Results of mean group scores indicated that subjects rated the CEB (26.55±4.98) significantly more favourable compared to the EB (38.45±4.74; p=0.010) in terms of comfort and preference.

In addition, a Kruskal-Wallis analysis by question was performed on group mean scores. Results of the analysis revealed that there were significant differences in questions 1, 2, 4, 5 and 6. CEB was rated higher than EB, meaning that players perceived feelings of increased comfort, confidence and skating performance in the CEB condition. There were no significant differences found for questions 3 and 7 between EB and CEB conditions, meaning that subjects did not perceive a difference in glide or increased confidence in their skating abilities. Question #8 assessed player effort; there were no significant differences found across blade conditions meaning that there was a consistent effort during testing sessions.

Player perception questionnaires also required subjects to rate their perceived skating abilities and confidence while skating on the experimental skate blades compared to the baseline condition. Frequency of questionnaire responses scored four or higher was tallied for the EB and CEB conditions to investigate player's perceptions of the experimental skate blades compared to the baseline condition. While skating on the EB condition 69% of subjects reported that the EB provided a feeling of a stronger grip with the ice. Following the CEB condition 75% of subjects reported that they were capable of performing tighter turns, 63% reported that they were able to skate faster, 88% reported that the CEB provided a feeling of a stronger grip with the ice and 53% reported a higher level of confidence in their skating ability (Figure 5). The questionnaire data revealed that 56% of players preferred the CEB when compared to the baseline condition. The questionnaire data on player's level of perceived exertion during on-ice testing sessions revealed no significant differences across EB and CEB blade conditions ($p \leq .05$).

CHAPTER V: DISCUSSION

Hockey can be viewed as a game of skating speed, where players move from one point to another in the shortest amount of time. Due to the dynamic nature of the game, even small increases in speed can potentially provide a player with a positional advantage that may affect game play. For example, faster players are typically the first to touch the puck or the first to position themselves in front of the net, increasing their chances of scoring a goal. This study has attempted to address the contribution of the material properties and preparation of skate blades to on-ice skating speed that may provide the player with a performance advantage. A battery of seven, isolated on-ice skating skill drills and one combination drill were conducted to investigate differences in skating speed across three blade conditions. The three blade conditions were (i) baseline, where players skated on their own skate blades prepared with their preferred sharpening characteristics, (ii) an experimental condition, where a unique pair of experimental skate blades were prepared with a standardized sharpening, and (iii) a customized condition, where experimental blades were prepared with the subject's preferred sharpening characteristics. Previous research investigating the isolated effects of different skate sharpening characteristics on skating speed has suggested that there are three variables that have the potential to interact with skating speed; radius of hollow, radius of contour and pitch. More specifically, customizing radius of hollow has the potential to create a longer stride length, improve stopping time and decrease stopping distance (Winchester & Lockwood, 2006) and adjusting the radius of contour as it relates to a player's weight has the potential to enhance skating on-ice speed (Lockwood & McKenzie, 2012). Pitch is defined as the apex of a skate blade; shifting the apex forward or backward along the blade changes the balance point or lye of the blade. There is currently no empirical research that has investigated the specific effect of pitch on on-ice skating speed, however the concept has been adopted from sprinters and the forward lean achieved by the use of starting blocks. Research to date has provided evidence to suggest that skate sharpening characteristic have the potential to contribute to on-ice skating performance and therefore, the premise of this study was to investigate the combined effect of the material properties of the experimental blades and customized sharpening characteristics, as it relates to on-ice skating speed.

Seven of the eight on-ice skating drills used to assess skating speed across blade conditions were classified as drills in isolation, meaning that athletes were required to perform a skill in isolation. These drills required athletes to perform relatively simple skills completed in a short period of time, ranging from 4.01 to 5.40 seconds. No significant differences in T1 (s) or TT (s) were revealed in insolation drills across the three blade conditions. Therefore, it may be suggested that the potential benefits of the material properties and the customization of the experimental skate blades were not impactful. However, a comparison between the total time (TT) to complete the individualized skating drills (4.01 to 5.40 seconds) versus the combination drill (19.26 to 19.49 seconds) may provide insight into the interpretation of the data collected. One potential explanation as to why statistical significance was not reached in the isolated skating drills could possibly be explained by sensitivity to change, meaning that a difference of milliseconds to complete the isolation drills may have been too slight to result in significant differences. Therefore, it could be viewed as more difficult to decrease the time to complete a shorter skating drill compared to decreasing the time it takes to complete a longer skating drill.

The combination drill consisted of multiple skills performed in sequence and was designed to mimic the skating skills commonly performed in a game like condition compared to the individualized skill drills. The drill required players to accelerate from the goal line in one end zone and pivot backwards at the first blue line. They skated backwards between the blue lines and pivoted forwards at the second blue line. Players then entered into the opposite end zone from where they skated through a five-pylon agility course. After the agility section, subjects skated as fast as possible the length of the ice. Significant differences were revealed in both T1(s) and TT (s) as measured during the combination drill across the three blade conditions. More specifically, a post hoc analysis revealed that the differences were found between the baseline condition and the customized experimental blade condition (CEB). No significant differences in T1 and TT times (s) were found between EB and baseline. No significant differences found between EB versus baseline may suggest that skate blade material properties do not significantly affect on-ice skating speed. However, it could be suggested that the combined effect of the material properties of the experimental skate blades prepared with subjects' preferred sharpening characteristics could potentially contribute to a decrease in time to complete the combination drill resulting in an increase skating speed. More specifically, in the EB condition participants skated on the experimental skate blades prepared with an unfamiliar standardized sharpening, when the experimental skate blades were prepared with subjects' preferred sharpening characteristics, a significant difference was revealed in on-ice skating speed. It is then reasonable to assume that while blade properties may be important, customizing the blade to the player's preference is also valuable.

In an attempt to translate the seemingly small decreases in time into a practical application, the time data collected during the combination drill was analyzed to represent distance. The results suggest that subjects were able to accelerate (T1) 3% faster when skating on the CEB condition in comparison to skating on their own skate blades during the baseline condition as measured during the combination drill. This increase in skating speed translates to a difference in distance of 0.15m, suggesting that a player skating on the customized experimental skate blades has the potential to cover a greater distance over the same amount of time. Time to complete (TT) the combination drill (s) revealed that, subjects were able to skate 1% faster compared to the baseline condition, translating to 1.28m difference in distance travelled over the 110m course. Although non-significant, differences in mean skating speed measured during the isolated start and stop drill revealed that players skating on the CEB condition produced the fastest skating speeds. During the 0.61m acceleration phase (T1), mean skating speeds translate to the skater covering a distance of 0.03m to 0.05m and over the course of the 21.95m drill (TT) mean skating speeds translate to the skater covering a distance of 0.09m to 0.12m ahead of the baseline condition. Although 0.03m to 0.12m are relatively small distances, in the context of a hockey shift it could be suggested that a player's ability to accelerate, change direction, and/or skate faster than an opposing player may create an opportunity for puck possession and a positional advantage to score a goal.

A player's perceived comfort in their equipment has the potential to significantly contribute to player's level of confidence to perform using select pieces of equipment.

Equipment choices are often selected based on familiarity, whether it is scientifically proven to work or not, players tend to choose equipment that they are used to and comfortable performing with. Baseline data was used to profile the player's preference and the blade sharpening characteristics that define their preference. A comparison of perceived comfort and perceived performance revealed that players reported that they were unsure if they felt more comfortable or increased their skating performance while skating on the EB condition versus baseline. However, the data collected after the CEB condition revealed that players reported a feeling of stronger grip with the ice, increased skating speed and a greater level of comfort in the customized experimental blades compared to the baseline condition. Not only did players perceive they skated faster, on-ice data collected during the combination drill revealed that players produced significantly faster skating times skating on the CEB condition, supporting the questionnaire ratings.

Acceleration time (T1) and total time to complete (TT) data collected during the combination drill revealed that players produced significantly faster skating times skating on the CEB condition, which was supported by no significant differences found in subjects' rate of perceived exertion (RPE) between the EB and CEB conditions. Meaning that subject RPE was consistent across blade conditions. This non-significant finding can be viewed as positive, suggesting that effort was not a contributing factor.

For the purpose of this study, a non-traditional randomization of sharpening characteristics was utilized. During the baseline condition, subjects skated on their own blades prepared with their preferred sharpening characteristics; during the EB condition, blades were prepared with standardized sharpening characteristics and during the CEB condition, participants skated on their preferred sharpening characteristics again, creating a randomization of blade sharpening. Resources limited the purchase of one pair of experimental skate blades per participant. Therefore, the customization trial had to follow the standardized trial; once a customized sharpening was applied to the EB, it would be impossible to return the blades to the original condition or the manufacturer's "out of the box" standard. It could be suggested that the inability to randomize the order of blade conditions could have contributed to an order-effect bias. In the context of the results, failure to implement a traditional randomized block design could have allowed players learn how to perform the drills faster and influence T1 and TT times. Data revealed a random distribution of acceleration and total times between blade conditions therefore, it could be suggested that there was no learning effect or any other effect of test order revealed during on-ice testing. One potential explanation for these results is that participants were competitive level hockey players who routinely perform the on-ice skills required for the assessments.

Equipment has been designed to harness physiological and technical aspects of game play and transfer it to sport performance; specific to this study the effect of the material properties and design of an experimental skate blade were investigated. The material properties of the experimental skate blades alone in comparison to subjects' current skate blades, did not support the hypothesis that, steel matters and may suggest that steel in fact does not matter. However, the CEB condition matched players' preferred sharpening characteristics to the experimental skate blade and significant differences were revealed. The results of this study suggest that hockey players can skate faster on experimental blades customized to subject's preferred sharpening characteristics in a drill created to simulate a shift in ice hockey and therefore skate blade material properties in combination with the customized sharpening might provide an advantage that contributes to faster skating speeds. This study provides further knowledge to understand the complex relationships between variables that have the potential to affect performance. Current research has provided inconclusive results with regard to the relationship between an athlete and their equipment, however the results of this study can provide knowledge to parents, players and coaches as to the contribution of the skate blade properties and customized sharpening to on-ice performance. Furthermore, investigating the longevity of edge may be warranted to determine whether the potential performance benefits have a lifespan relative to the retention of the blade's sharpening characteristics.

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Table 1. Skate blade sharpening characteristics

Descriptive	Frequency (n)
Single ROC	
≤2.44m (≤9 ft)	3
2.74m (9 ft)	19
≥3.05m (≥10 ft)	4
Double ROC	
2.74-3.05 (9-10 ft)	6
ROH	
≤0.95cm (3/8”)	3
1.27cm (1/2”)	19
≥1.59cm (5/8”)	10
Edge levelness	
Yes	13
No	21

ROC = Radius of Contour; ROH = Radius of Hollow

Table 2. Mean acceleration Time (T1) and Total Time (TT) to complete across blade conditions (mean±SD)

Conditions	Baseline		Experimental Blade		Customized Experimental Blade	
Skills	T1	TT	T1	TT	T1	TT
Forwards (s)	0.659	4.785	0.653	4.783	0.607	4.807
	(0.16)	(1.33)	(0.15)	(0.11)	(0.14)	(0.15)
Backwards (s)	0.956	5.847	0.944	5.828	0.959	5.876
	(0.11)	(0.34)	(0.09)	(0.26)	(0.10)	(0.30)
Forward Agility (s)	0.667	5.159	0.685	5.194	0.668	5.206
	(0.16)	(0.17)	(0.17)	(0.18)	(0.15)	(0.16)
Stop/Start Left (s)	0.698	5.385	0.696	5.399	0.671	5.364
	(0.13)	(0.20)	(0.14)	(0.13)	(0.13)	(0.16)
Stop/Start Right (s)	0.702	5.376	0.683	5.389	0.647	5.338
	(0.14)	(0.21)	(0.13)	(0.14)	(0.11)	(0.14)
Cross-Over Left (s)	0.725	4.052	0.711	4.090	0.729	4.111
	(0.13)	(0.19)	(0.13)	(0.20)	(0.13)	(0.11)
Cross-Over Right	0.697	4.012	0.668	4.052	0.669	4.080
(s)	(0.13)	(0.16)	(0.10)	(0.17)	(0.11)	(0.13)
Composite (s) Sum	5.104	5.040	4.950	35.616	34.745	34.782
of *Skill T1, TT*	(0.102)	(0.101)	(0.177)	(0.699)	(0.683)	(0.674)
Combination (s)	1.912	19.487	1.911	19.323	1.860	19.263
Skill run in series	(0.07)	(0.54)	(0.10)	(0.54)	(0.07)*	(0.55)*
			*			**

*B, EB T1> CEB T1 (delta 0.014s); **B, EB TT> CEB TT combinations (delta 0.050s)

Table 3. Individual Acceleration Time (T1) across blade conditions

Subject ID	BFWO1	RFWO1	CFWO1	BBWO1	RBWO1	CBWO1	BFAGWO1	RFAGWO1	CFAGWO1	BFSSOL1	RFSSOL1	CFSSOL1	BFSSOR1	RFSSOR1	CFSSOR1	BFXOOL1	RFXOOL1	CFXOOL1	BFXOOR1	RFXOOR1	CFXOOR1	BSABRE1	RSABRE1	CSABRE1
5005	0.458	0.460	0.785	0.944	0.978	1.018	0.444	0.537	0.855	0.648	0.669	0.842	0.463	0.456	0.785	0.634	0.813	0.630	0.845	0.655	0.794	1.952	1.934	1.715
5007	0.607	0.513	0.577	0.964	0.969	1.034	0.609	0.528	0.407	0.602	0.537	0.749	0.722	0.574	0.603	0.820	0.798	0.709	0.791	0.768	0.682	1.939	1.951	1.922
5012	0.416	0.444	0.581	0.809	0.821	0.941	0.660	0.590	0.575	0.408	0.407	0.478	0.777	0.723	0.669	0.690	0.735	0.458	0.717	0.622	0.600	1.968	1.919	1.924
5016	0.319	0.654	0.420	0.797	0.695	0.872	0.537	0.410	0.449	0.518	0.659	0.508	0.863	0.747	0.680	0.683	0.799	0.474	0.880	0.756	0.605	1.912	1.816	1.886
5019	0.476	0.490	0.570	0.747	0.897	1.117	0.439	0.530	0.848	0.674	0.670	0.787	0.509	0.508	0.827	0.771	0.794	0.718	0.763	0.700	0.788	1.895	1.897	1.760
5021	0.519	0.407	0.532	1.027	1.015	1.074	0.598	0.420	0.621	0.756	0.467	0.783	0.681	0.472	0.764	0.700	0.756	0.543	0.654	0.799	0.800	1.886	1.923	1.806
5025	0.345	0.313	0.475	0.919	0.920	0.928	0.401	0.393	0.546	0.611	0.725	0.659	0.661	0.660	0.537	0.724	0.552	0.596	0.674	0.663	0.521	1.946	1.963	1.964
5044	0.459	0.446	0.795	0.881	0.881	1.164	0.437	0.501	0.672	0.700	0.695	0.712	0.538	0.584	0.540	0.788	0.897	0.800	0.720	0.752	0.770	1.947	1.861	1.945
5008	0.682	0.684	0.761	1.105	0.847	1.032	0.837	0.906	0.731	0.630	0.828	0.802	0.739	0.791	0.859	0.682	0.650	0.772	0.591	0.718	0.652	1.960	1.988	1.872
5009	0.674	0.608	0.377	0.949	0.809	0.962	0.635	0.759	0.679	0.670	0.508	0.509	0.481	0.456	0.493	0.407	0.487	0.544	0.552	0.575	0.401	1.842	1.842	1.825
5013	0.735	0.832	0.391	1.064	0.993	0.960	0.771	0.950	0.563	0.684	0.900	0.610	0.802	0.853	0.672	0.654	0.564	0.604	0.598	0.541	0.582	1.987	1.990	1.970
5047	0.861	0.889	0.687	0.852	0.941	0.946	0.605	0.960	0.718	0.714	0.884	0.522	0.479	0.838	0.439	0.652	0.535	0.675	0.610	0.679	0.709	2.068	1.936	1.901
5057	0.640	0.622	0.532	1.166	1.054	1.077	0.740	0.775	0.731	0.810	0.732	0.836	0.660	0.773	0.586	0.727	0.562	0.798	0.687	0.683	0.741	1.915	1.814	1.745
5062	0.749	0.826	0.432	1.106	0.949	0.966	0.728	0.730	0.733	0.738	0.896	0.676	0.810	0.837	0.704	0.731	0.626	0.691	0.556	0.446	0.451	2.002	1.854	1.916

5088	0.693	0.757	0.879	1.237	0.946	1.040	0.593	0.676	0.590	0.492	0.480	0.732	0.609	0.659	0.732	0.620	0.601	0.776	0.423	0.448	0.478	1.957	1.896	1.903
5055	0.76	0.656	0.76	0.956	0.966	0.9	0.531	0.722	1.029	0.775	0.781	0.759	0.606	0.8	0.762	0.563	0.805	0.812	0.533	0.543	0.769	1.775	1.884	1.889
5009	0.739	0.577	0.643	0.948	0.799	0.811	0.681	0.574	0.676	0.758	0.49	0.533	0.699	0.757	0.625	0.802	0.876	0.893	0.69	0.692	0.604	1.805	2.01	1.898
5014	0.72	0.564	0.818	1	1.042	1.025	0.906	0.712	0.874	0.798	0.558	0.785	0.798	0.522	0.799	0.855	0.554	0.822	0.739	0.672	0.701	1.84	1.921	1.834
5016	0.691	0.528	0.735	0.86	0.935	0.962	0.53	0.619	0.712	0.806	0.475	0.754	0.539	0.557	0.577	0.761	0.506	0.8	0.523	0.46	0.662	1.748	1.824	1.792
5017	0.711	0.477	0.719	0.931	0.831	0.819	0.751	0.457	0.719	0.744	0.762	0.871	0.76	0.476	0.781	0.778	0.694	0.835	0.705	0.658	0.731	1.845	1.818	1.79
5021	0.728	0.831	0.583	1.062	1.08	0.965	0.806	0.782	0.587	0.767	0.802	0.788	0.816	0.822	0.596	0.647	0.86	0.879	0.707	0.747	0.762	1.871	1.889	1.929
5024	0.791	0.718	0.45	0.802	0.868	0.684	0.858	0.714	0.462	0.768	0.787	0.568	0.793	0.754	0.548	0.777	0.814	0.875	0.707	0.657	0.746	1.862	1.916	1.772
2002	0.518	0.814	0.489	0.941	0.982	0.846	0.767	0.984	0.724	0.788	0.717	0.696	0.831	0.791	0.629	0.863	0.827	0.861	0.771	0.78	0.686	1.914	1.837	1.807
4004	0.69	0.773	0.678	0.886	0.919	0.86	0.69	0.886	0.986	0.516	0.829	0.467	0.627	0.823	0.568	0.764	0.787	0.777	0.666	0.737	0.686	1.871	1.858	1.822
4008	0.733	0.815	0.653	0.852	0.901	0.831	0.749	0.91	0.739	0.739	0.799	0.783	0.649	0.812	0.609	0.923	0.889	0.917	0.786	0.821	0.741	1.973	1.96	1.962
4011	0.567	0.789	0.744	0.947	1.09	0.999	0.493	0.467	0.482	0.568	0.781	0.474	0.632	0.801	0.571	0.654	0.844	0.878	0.719	0.774	0.757	1.908	1.941	1.921
4017	0.668	0.654	0.413	0.916	1.052	0.893	0.495	0.762	0.521	0.524	0.528	0.436	0.685	0.61	0.507	0.594	0.649	0.687	0.394	0.657	0.437	1.811	1.798	1.721
5010	0.791	0.774	0.587	0.894	0.93	0.924	0.459	0.779	0.484	0.741	0.79	0.573	0.542	0.525	0.461	0.61	0.796	0.864	0.676	0.74	0.698	1.908	1.878	1.886
5014	0.727	0.698	0.481	1	1.047	0.946	0.805	0.751	0.634	0.648	0.824	0.755	0.801	0.785	0.729	0.576	0.802	0.868	0.68	0.722	0.694	1.92	1.848	1.804
6002	0.705	0.765	0.597	1.103	1.07	1.05	0.733	0.802	0.727	0.783	0.758	0.689	0.749	0.727	0.66	0.557	0.535	0.509	0.608	0.517	0.709	1.865	1.896	1.88

2017	0.912	0.757	0.7	1.198	1.004	1.033	0.959	0.732	0.705	0.976	0.81	0.676	0.968	0.617	0.714	0.826	0.665	0.582	0.901	0.728	0.771	1.971	1.899	1.935
5022	0.66	0.759	0.571	0.893	0.983	1.012	0.599	0.611	0.6	0.728	0.736	0.68	0.738	0.746	0.691	0.764	0.672	0.709	0.69	0.654	0.698	1.865	2.385	1.822

Table 4. Individual Total Time (TT) to complete across blade conditions

Subject ID	BFWOT	RFWOT	CFWOT	BBWOT	RBWOT	CBWOT	BFAGWOT	RFAGWOT	CFAGWOT	BFSSOLT	RFSSOLT	CFSSOLT	BFSSORT	RFSSORT	CFSSORT	BFXOOLT	RFXOOLT	CFXOOLT	BFXOORT	RFXOORT	CFXOORT	BSABRET	RSABRET	CSABRET
5005	4.580	4.744	4.803	5.399	5.556	5.701	5.004	5.119	5.151	5.308	5.280	5.684	5.125	5.314	5.447	3.702	3.796	4.077	3.889	3.832	4.298	19.35	18.91	18.732
5007	4.981	4.909	5.080	6.021	6.225	6.482	5.084	5.167	5.253	5.767	5.509	5.773	5.850	5.381	5.503	3.853	3.808	4.207	3.838	3.770	4.113	19.649	19.354	19.915
5012	4.783	4.783	4.898	5.826	5.765	6.093	5.242	5.167	5.308	5.390	5.364	5.397	5.390	5.282	5.198	3.796	3.764	4.033	3.684	3.689	3.953	18.978	19.523	18.541
5016	4.804	4.818	4.848	6.097	6.006	5.995	5.321	5.058	5.029	5.447	5.425	5.258	5.360	5.441	5.242	3.677	3.986	4.095	4.112	3.926	4.001	19.779	18.964	19.420
5019	4.778	4.751	4.742	5.476	5.696	5.510	4.897	4.974	5.115	5.172	5.157	5.389	5.325	5.268	5.455	3.718	3.693	4.110	3.698	3.798	4.207	19.811	18.343	18.847
5021	4.845	4.854	4.695	6.117	6.072	5.730	5.276	5.144	5.138	5.642	5.446	5.362	5.491	5.558	5.413	4.125	3.926	4.174	4.037	3.986	4.144	19.737	19.584	19.103
5025	4.921	4.816	5.101	6.104	6.052	6.001	5.138	5.290	5.401	5.521	5.519	5.332	5.467	5.498	5.389	3.825	3.741	4.248	3.691	3.824	4.111	20.034	18.844	19.394
5044	4.624	4.676	4.773	5.422	5.500	5.861	4.883	4.977	5.176	5.259	5.302	5.270	5.483	5.292	5.487	3.806	3.885	3.815	3.906	3.884	3.923	19.333	18.792	19.530
5008	4.782	4.920	4.973	6.041	5.745	6.000	5.390	5.440	5.388	5.372	5.555	5.687	5.443	5.505	5.706	4.090	4.107	4.170	4.078	4.326	4.115	19.366	19.365	18.870
5009	4.674	4.667	4.670	5.560	5.525	5.555	5.063	5.158	5.091	5.513	5.407	5.357	5.260	5.300	5.394	4.060	4.105	4.003	3.906	3.997	3.936	19.223	18.875	18.466
5013	4.840	4.836	4.950	6.380	5.940	6.165	5.175	5.179	5.115	5.473	5.492	5.340	5.398	5.515	5.420	4.207	4.097	4.064	4.184	4.023	4.134	19.518	19.447	19.151
5047	5.101	4.924	4.973	6.000	5.741	5.858	5.340	5.409	5.255	5.528	5.681	5.394	5.309	5.508	5.327	4.076	4.115	4.100	3.896	4.230	4.084	19.402	19.936	19.294
5057	4.591	4.544	4.592	6.082	5.750	5.795	5.135	5.078	5.049	5.503	5.417	5.539	5.580	5.652	5.439	4.375	4.156	4.201	4.156	4.221	4.287	19.446	18.854	19.682
5062	4.950	4.933	4.947	6.303	6.171	6.288	5.415	5.373	5.485	5.553	5.646	5.475	5.626	5.612	5.540	4.123	4.135	4.116	4.116	4.177	4.163	19.873	19.466	19.844

5088	4.722	4.672	4.995	6.081	5.840	5.915	5.063	4.937	5.019	5.171	5.521	5.314	5.173	5.620	5.183	4.019	4.170	4.005	3.821	4.004	3.856	19.253	18.794	18.455
5055	4.535	4.541	4.569	5.362	5.453	5.558	5.23	5.298	5.466	5.136	5.256	5.285	5.29	5.283	5.158	4.015	4.18	4.207	4.118	4.054	4.139	18.454	18.669	18.592
5009	4.575	4.723	4.686	5.68	5.596	5.756	5.116	5.12	5.12	5.339	5.183	5.06	5.116	5.162	5.202	4.056	4.083	4.089	4.025	4.111	3.907	18.857	18.993	18.779
5014	4.802	4.99	5.015	5.885	5.773	6.025	5.412	5.282	5.404	5.337	5.401	5.429	5.446	5.542	5.497	4.237	4.418	4.347	4.244	4.316	4.228	19.895	20.428	19.663
5016	4.633	4.623	4.727	6.018	6.06	6.087	5.283	5.173	5.138	5.275	5.334	5.242	5.208	5.193	5.236	4.089	4.123	4.119	4.097	4.019	4.008	19.035	19.329	18.829
5017	4.698	4.757	4.721	5.986	6.003	6.023	5.145	4.966	5.217	5.327	5.323	5.586	5.487	5.352	5.392	4.12	4.154	4.201	4.219	3.999	4.195	21.065	19.966	19.553
5021	4.766	4.766	4.804	6.076	6.255	5.935	5.074	4.982	5.039	5.225	5.375	5.355	5.208	5.315	5.257	3.867	4.129	3.954	3.888	4.023	4.045	20.118	19.89	20.097
5024	4.806	4.792	4.796	5.584	5.652	5.533	5.258	5.04	5.052	5.279	5.375	5.317	5.368	5.419	5.267	4.129	4.084	4.113	4.059	3.992	4.157	19.167	19.132	19.203
2002	4.776	4.722	4.675	5.911	5.704	5.63	5.245	5.465	5.358	5.11	5.291	5.191	5.341	5.182	5.234	4.113	4.11	4.084	4.12	4.088	4.071	19.384	18.613	18.674
4004	4.703	4.714	4.707	5.5	5.493	5.567	4.87	5.09	5.199	5.419	5.411	5.254	5.295	5.269	5.25	3.994	4.011	3.973	3.985	4.016	3.938	18.703	18.795	18.925
4008	4.822	4.854	4.802	5.376	5.35	5.357	5.297	5.359	5.196	5.344	5.337	5.275	5.349	5.268	5.327	4.128	4.293	4.048	4.029	4.031	3.939	19.308	19.731	19.641
4011	4.76	4.905	4.821	5.648	5.717	5.651	5.186	5.373	5.168	5.359	5.476	5.33	5.298	5.374	5.236	4.283	4.206	4.108	4.163	4.231	4.218	19.238	19.481	19.182
4017	4.561	4.625	4.463	5.465	5.687	5.334	4.751	4.936	4.806	5.034	5.16	5.067	5.002	5.139	5.098	4.115	4.083	4.046	3.881	3.909	3.826	18.979	18.883	18.427
5010	4.762	4.784	4.715	5.593	5.871	5.728	5.164	5.41	5.08	5.232	5.267	5.178	5.327	5.26	5.229	4.063	4.077	3.968	4.061	4.122	4.01	19.319	19.62	19.672
5014	4.833	4.888	4.74	5.756	5.873	5.989	5.336	5.614	5.515	5.48	5.424	5.364	5.467	5.413	5.058	4.45	4.587	4.359	4.219	4.381	4.268	19.942	19.313	19.69
6002	4.844	4.85	4.845	6.504	6.205	6.407	5.425	5.404	5.454	5.398	5.564	5.495	5.421	5.463	5.457	4.297	4.283	4.155	4.198	4.197	4.092	20.209	20.416	20.291

2017	4.793	4.87	4.874	5.916	5.802	5.97	5.138	5.128	5.268	5.638	5.487	5.412	5.619	5.488	5.419	4.172	4.361	4.209	4.172	4.231	3.949	20.23	19.905	20.272
5022	4.797	4.79	4.812	6.224	6.417	6.532	5.101	5.089	5.144	5.542	5.407	5.252	5.424	5.577	5.343	4.267	4.214	4.149	4.182	4.265	4.247	19.613	20.115	19.673

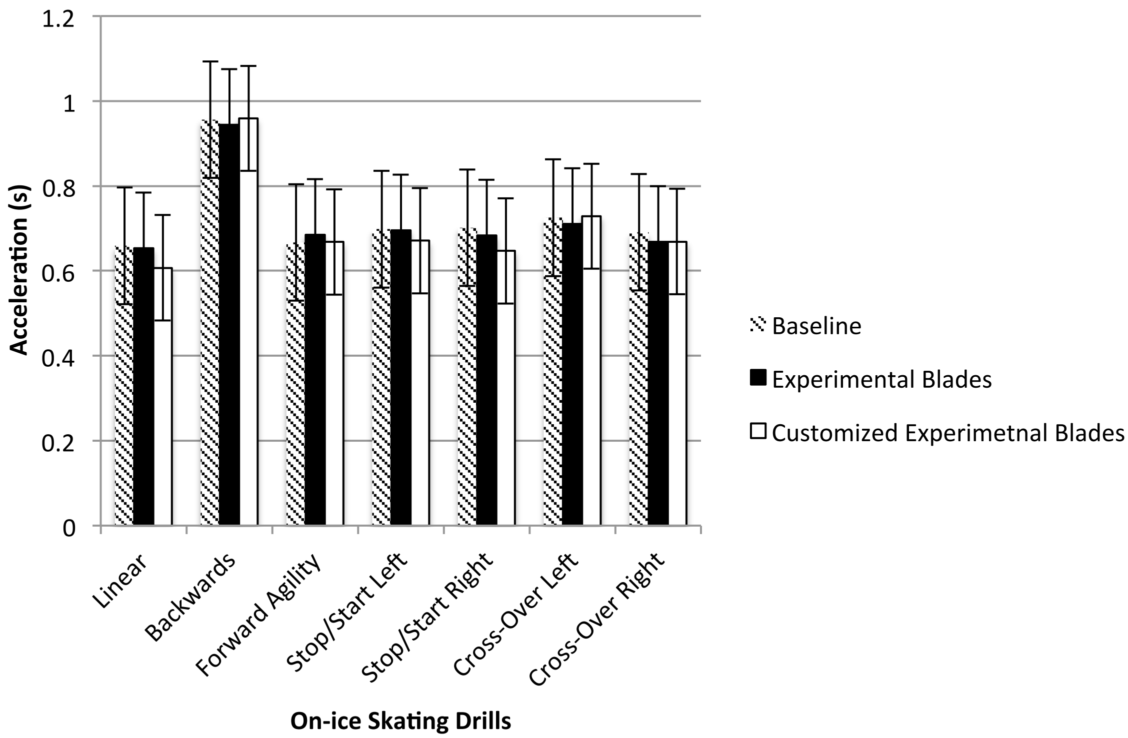

Figure 1. Acceleration Time (T1; measured in seconds) measured during the isolation drills across blade conditions

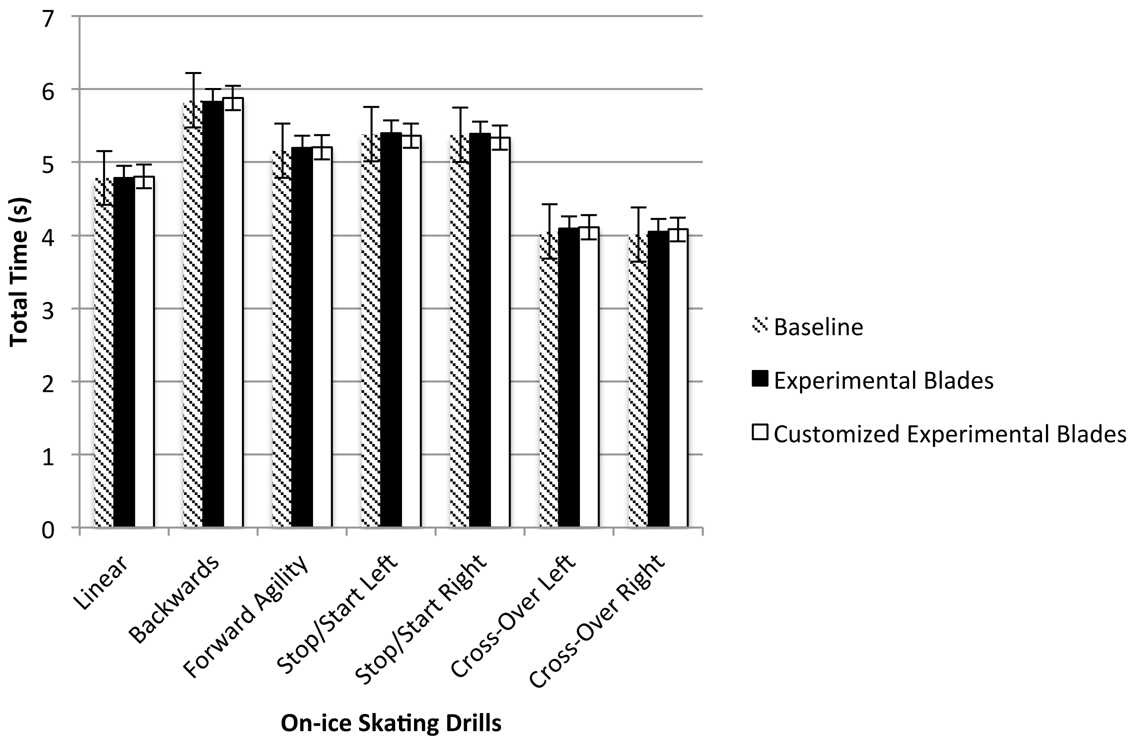

Figure 2. Total Time to complete (TT; measured in seconds) measured during the isolation drills across blade conditions

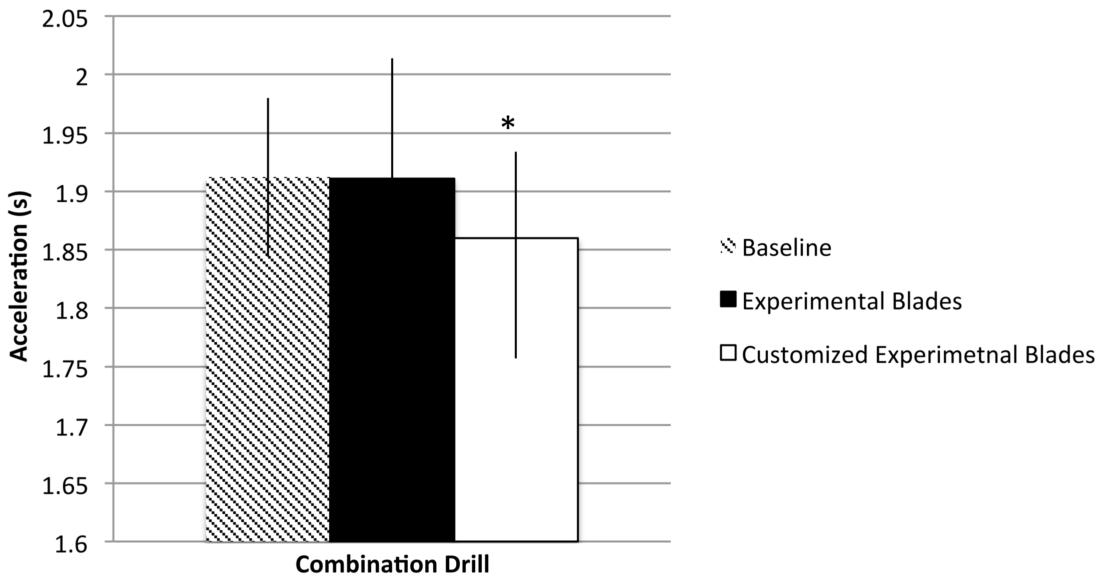

Figure 3. Acceleration Time (T1; measured in seconds) time measured during the combination drill across blade conditions (*$p \leq .05$)

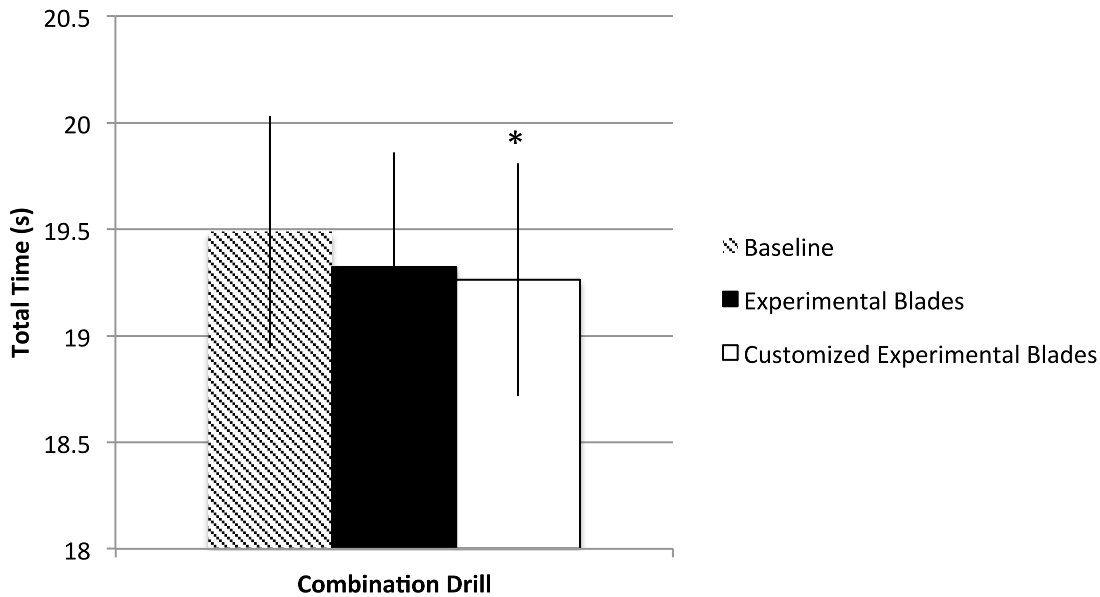

Figure 4. Total Time to complete (TT; measured in seconds) measured during the combination drill across blade conditions (* $p \leq .05$)

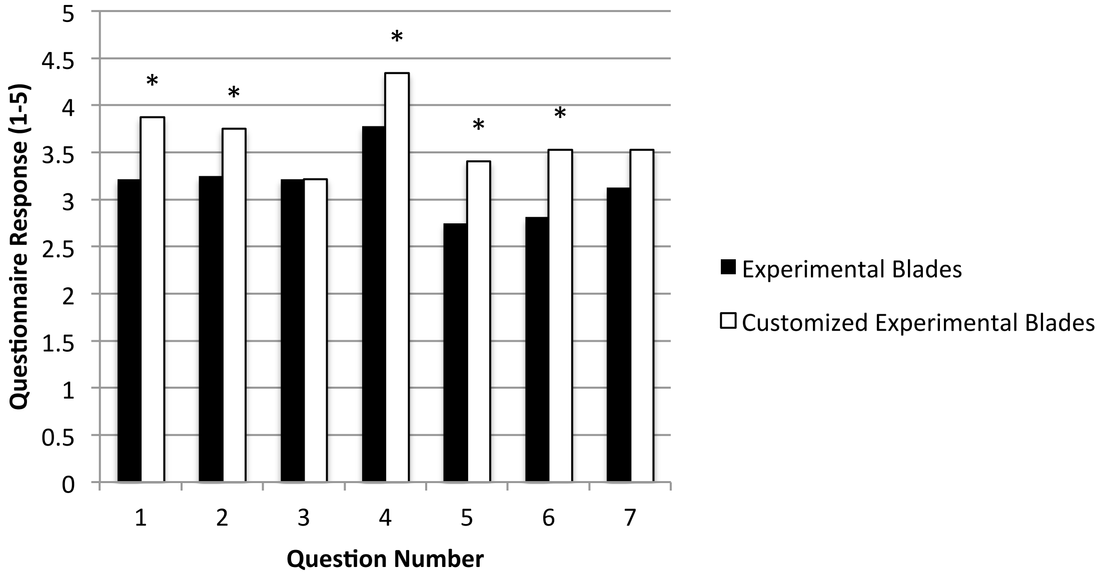

Figure 5. Mean questionnaire responses of subject feedback in EB and CEB conditions. All responses were compared to the baseline condition and rated on a Likert scale (1 to 5). Questions
1-5 investigated perceived performance in the blades and questions 6 and 7 investigated perceived comfort while skating on the experimental skate blades (* $p \leq .05$).

APPENDICES

Appendix A

Player Questionnaire

Please circle your answer to the following questions on a scale of 1 to 5.
1= strongly disagree
2= slightly disagree
3= not sure
4= slightly agree
5= strongly agree

1. I felt that my experimental skate blades allowed me to turn tighter in comparison to my current skate blades.
1 2 3 4 5

2. I felt that my experimental skate blades allowed me to skate faster in comparison to my current skate blades.
1 2 3 4 5

3. I felt that my experimental skate blades glided across the ice better in comparison to my current skate blades.
1 2 3 4 5

4. I felt that my experimental skate blades had a stronger grip on the ice in comparison to my current skate blades.
1 2 3 4 5

5. I felt that my experimental skate blades allowed me to skate faster backwards in comparison to my current skate blades.
1 2 3 4 5

6. I feel more confident in my skating abilities on my experimental skate blades in comparison to my current skate blades.
1 2 3 4 5

7. I prefer how my experimental skate blades felt in comparison to my current skate blades.
1 2 3 4 5

8. Rate your skating effort during today's testing session.
1 2 3 4 5 6 7 8 9 10

Appendix B

Skating Drills

Linear Speed

The linear speed test will be an on-ice sprint. Skaters will begin on the starting mark painted on the ice. They will begin in a two-foot stance, facing parallel to the direction of travel with one hand on their hockey stick. A timing light will indicate when the player will start the test. Players will skate from starting mark to the furthest blue line. Skater's linear speed (total time) and two-step acceleration will be measured using the Swift timing light system.

Backwards Test

The backwards test will be similar to the Linear Speed test, subjects begin with their heels on the starting line facing in the opposite direction of travel and instructed to skate backwards.

Agility Test

The players will start on the starting mark created on the ice in a two-foot stance, facing parallel to the direction of travel. The timing light will indicate when the player will start. Players will travel through a seven-pylon agility pattern as quickly as possible.

Stop/Start Test

Players will begin on the starting mark facing perpendicular to the direction of travel. When the timing system indicates a player should start, they will cross over quickly and accelerate to the blue line closest to them. They will stop with both feet over the blue line and change directions quickly to skate back to the starting mark. Players will repeat this test facing the opposite direction.

In-zone Cross Over Test

Subjects will begin with their feet horizontal on the hash marks on the circle in one of the defensive zones, facing the boards. When the light indicates the start of the test, players will perform crossovers across the bottom of the circle and accelerate to above the top of the circles. Subjects will glide to the hash marks on the opposite circle and after at five second rest will perform the test again crossing over and accelerating in the opposite direction.

Combination Test

Players will combine forward acceleration, backwards speed, agility and linear speed in this test. Players will be asked to start lined up on the goal line in one end zone. A timing light will initiate the start of the movement and players will accelerate to the first blue line and pivot backwards. They will then skate backwards between the blue lines and will pivot forwards at the second blue line. Players will then enter into the opposite end zone from where they started and skate through a five-pylon agility course. After the agility section, subjects will skate as fast as possible the length of the ice.