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When Metal Meets Ice: Potential for Performance or Injury

ABSTRACT: Physical conditioning, technical ability, contact, and protective equipment have been identified through research as factors that can potentially contribute to the incidence of injuries in ice hockey players. One safety-related factor often overlooked is the interaction between the skate blade and the ice. Skating is one of the fundamental skills of a successful hockey player, but the effect of skate sharpening on blade characteristics and performance has received limited research attention. The point of contact with the ice is essentially what allows the transition of human motion to skating mechanics, and it may affect both the quality of skating performance and the potential for on-ice injuries. The purpose of this paper is to address the influence of skate blade sharpening characteristics on performance. Experiments performed to examine skate blade sharpening characteristics have identified radius of hollow (ROH), radius of contour (ROC), pitch and levelness of edges as variables that can be manipulated, quantified, and controlled when analyzing blade-ice interaction and the effect of skate sharpening on skating performance. Optimum values for each may produce more effective skating performances. Less than optimum values can result in slower speeds, longer stopping times, instability, body malalignment, greater fatigue, and potentially, greater chance of injury. Being able to define blade characteristics and determine the best combination of ROH, ROC, and pitch for a specific player allows some degree of control in an environment which can often be unpredictable. Furthermore, although there are standards for acceptable ice in professional hockey leagues, very often players must skate on a surface which is not only less than ideal, but which can also change over the course of a game or practice. Careful sharpening to accommodate for less than ideal ice conditions and the unpredictable nature of the play may also help to prevent fatigue, and injuries.

KEYWORDS: skate sharpening, radius of hollow, radius of contour, pitch

Introduction

To date, scientific literature published on the sport of ice hockey has focused primarily on the physiology [1–6], the biomechanics of on-ice movement [7–10], the performance characteristics of the players ([11–14], Naud and Holt, 1979, 1980 [15,16]) and the prevalence of, and potential for, injury [17–20]. Limited research has been devoted to what appears to be an essential component, the athletes' point of contact with the ice. Blade runners and sharpening characteristics could be classified as one of the most important elements of any player's game. Although it is assumed that customization of the blade-holder and blade has been primarily motivated by the player and performance demands of the sport, too frequently forces other than science are the major drivers of product innovation in the athletic industry, resulting in limited supporting experimental data. Blade design, mounting, and sharpening appear to be more of an art than a science, yet they are readily accepted, without question, by the practitioner and consumer. Furthermore, research to demonstrate the influence of blade geometry and blade sharpening on the characteristics of motion necessary to optimize performance and decrease the potential for injury in on-ice sports is very limited [7,21]. In summary, inadequate research has been conducted using blade-ice interaction as a performance measure and no studies have addressed the influence of blade sharpening on the potential for injury. Preliminary investigations from our lab show that variables that define the blade-ice relationship can be quantified and translated into a performance difference and warrant further investigation.

Technical literature on skate sharpening published by Broadbent [22–24] is descriptive, informative, and practical; however, it does not include research-based evidence to support best practices in skate sharpening. Broadbent [22] has questioned why, after three centuries of skating on iron and steel blades,

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FIG. 1—*Skate blade radius of contour (ROC) (lateral view).*

there are no established standards for skate sharpening characteristics, and little information regarding its effect on skating performance. The lack of sharpening standards has also been identified in practical articles examining skate sharpening and skating [25,26]. It is this paucity of research examining the effects of skate blade sharpening characteristics on performance and the potential for injury that inspired this investigation.

Anatomy of the Skate Blade

The early work of Broadbent [22,23] outlined the dimensions and characteristics of the skate blade. The skate blade consists of three basic dimensions: height, length, and width. When the skate blade is sharpened, these dimensions can be altered to define two radii, radius of contour (ROC) and radius of hollow (ROH). Specific aspects of both these radii are proposed to govern the performance of the skate blade and define the blade-ice interaction.

The radius of contour (ROC), more commonly referred to as the rocker or the profile of the blade, describes the longitudinal shape of the blade and defines how much of the blade is in contact with the ice (Fig. 1). This means, for example, that if you were to place several blades all contoured with a 3.0 m (10 ft) radius toe to heel in a circle, the end result would be a circle with a radius of 3.0 m (10 ft). A demographic analysis of geometry of the skate blades of players on 12 NHL teams [27] identified a range of ROC for forwards and defensemen of 2.44–3.66 m (8–12 ft). On a 2.44 m (8 ft) ROC, there is less blade contact with the ice than on a 3.66 m (12 ft) ROC. In theory, the shorter 2.44 m (8 ft) ROC allows for greater agility, whereas the longer 3.66 m (12 ft) ROC has more blade in contact with the ice, allowing the skater to potentially achieve greater velocity.

Traditionally a good sharpening was defined as an even and uniform contour; however, the current practice of shaping the blade with multiple contours has shown this idea to be old fashioned. Multiple contours provide the skater the opportunity to access the benefits of skating on longer and shorter contours by simply shifting the weight to a specific area of the blade. It is imperative, however, that regardless of the number of contours, the blade be free of humps and bumps in the rocker. This is typically caused by uneven pressure applied to the grinding wheel when sharpening and translates to the skater feeling as if they are skating on an uneven ice surface.

The radius of hollow (ROH) is the groove in the width of the blade defining the two edges, the outside

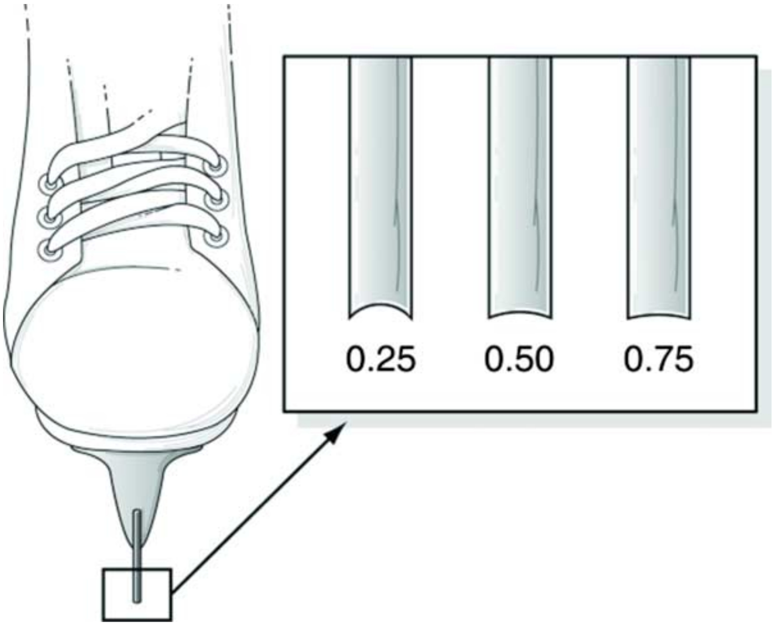

FIG. 2—*Skate blade radius of hollow (ROH) (frontal view). Units for the .25, .50, and .75 is inches.*

edge and the inside edge (Fig. 2). This groove can be deep or shallow depending on the desired effect. The deeper the ROH, the higher the edges, creating more of a bite angle between the edge and the ice. With the more acute bite angle, the skater will "hold" the ice better, and feel more confident during starts, stops, and turns. However, this angle also causes more dig into the ice and thus it takes more energy to accelerate and as a result, speed is often sacrificed.

The ROH is created by the radius of the grinding wheel. A short radius creates a deeper groove or hollow. Conversely, a longer radius will result in a shallower or flatter edge. Demographic analysis has also shown that the hollows most frequently used by elite level defensemen and forwards are 0.0127 m (1/2 in.) or 0.0158 m (5/8 in.) [27]. ROH was negatively correlated with body weight, indicating that lighter players prefer deeper hollows whereas heavier players prefer more shallow hollows. Due to the very different skill set of goalies, their hollows were also significantly different. Goalies tend to prefer either very shallow hollows to facilitate the ease of lateral movement in front of the net or very deep hollows to facilitate the butterfly technique used by some.

The pitch of the skate is determined by the height of the blade and the position of the apex or pivot point (Fig. 3). It has the ability to change the lie of the blade on the ice or pitch angle of the skate boot and directly affect the balance of the skater. If the height of the blade is greater at the front than at the back, a backwards tilt will be created. The proper lie allows the skater to be more efficient in movement and make the transitions between forward and backward skating easily.

The pitch of the blade is altered by grinding off the height from either the fore or aft portion of the blade. The change in height can result in an anterior/posterior shift in the skater's point of balance on the blade or apex of the blade. Position specific analyses suggest that there might be some advantage to adjusting the apex to facilitate the different skating techniques and technical demands required by position

FIG. 3—*Pitch or skate blade height (lateral view).*

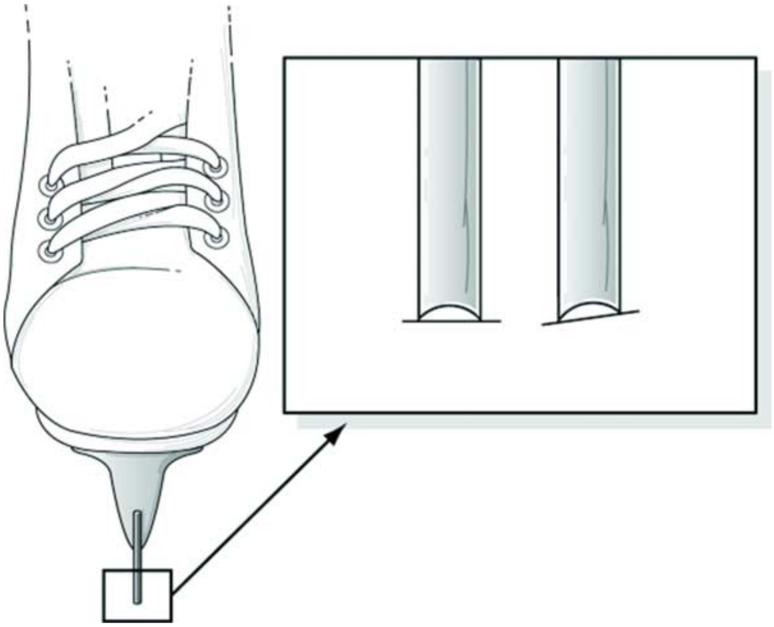

FIG. 4—*Levelness of edges.*

(i.e., forwards versus defense). Defensemen tend to move the apex of the contour forward of center to shift the body weight onto the balls of the feet.

Finally, the levelness of the edges refers to the height of the inside versus the outside edge (Fig. 4). Even edges are deemed desirable and are a result of quality sharpening. Often a skater's inability to turn in both directions with the same ease or to use both edges equally is blamed on poor technique or ability when, in fact, it could be a result of poor sharpening.

Blade-Ice Interaction

There are four published theories [28–30] that define how the blade interacts with the ice surface. All four theories are based on the premise that a thin film of water is created between the skate blade and the ice surface which causes a reduction in friction.

Broadbent [24] suggested that the skate blade ROH should be changed as the ice temperature changes. If the ice temperature (density) of an arena is colder (denser), then the ROH should be deeper. The deeper hollow creates a more acute blade edge angle, and the "keener" edge will interact with the denser ice more effectively. If the ice is warmer (less dense), a shallow hollow would be more appropriate, as the shallower hollow will not dig into the ice as aggressively as the deeper hollowed blade. Broadbent [24] stated that it is the blade-ice interaction and the friction between the two surfaces that can affect a skater's energy expenditure levels during skating.

Personal communications with facility operators at NHL arenas indicated that there are standards for ice conditions; some controllable and some which are not so easily controlled. Controllable factors include amount of ice (thickness), water temperature used to resurface ice, and water composition. The standard for ice thickness is 1.91 cm (3/4 in.). Even though it is only the top 0.64 cm (1/4 in.) that players skate on, i.e., the "green ice," less than standard depth can be problematic. Although it is assumed that ice thickness is controllable, given the multi-purpose nature of many facilities and quick turn-around time to prepare ice, ice thickness and quality is often compromised due to event schedules. Temperature for resurfacing is optimal at 140–180°F (60–82.2°C) and treated water makes ice more agreeable as opposed to nontreated water which results in "chippy or flakey" ice. Most facilities are equipped with deionizing equipment to control for water quality as standards for city water are much more variable.

Less controllable factors that can create problematic ice conditions include dew point, humidity, and temperature, all of which change with doors opening, number of people in the building, and air flow of the building, and require significant troubleshooting. Facility operation managers are often criticized for variables which are largely out of their control.

Skate Sharpening Research

The early work of Broadbent provided a foundation and operational definitions for experimental research to be conducted. However, studies conducted on skate sharpening characteristics using players performing game skills with different contours and hollows are limited. Gagnon and Dore [7] used a mechanical model to simulate the hockey stop performed on selected hollows. Results indicated that a deeper ROH (1.27 cm) resulted in a shorter stopping distance in comparison to a shallower ROH (3.81 cm). It was proposed that the deeper ROH causes the blade edge to carve deeper into the ice and results in a shorter stopping distance. Given that the typical game includes stopping and starting, it is possible that the depth of the ROH can affect a skater's performance.

More recently, players have been using an alternative training surface to supplement their on-ice training. Synthetic or plastic ice provides a similar feel and a low friction surface that simulates real ice [31]. Morrison et al. [21] investigated the effect of ROH on oxygen consumption while skating on a hockey specific skating treadmill surfaced with synthetic ice. Participants skated at three different velocities to determine the influence of three different ROH's on performance at different levels of exertion. The results indicated that the ROH had no significant effect on oxygen consumption during forward skating on the treadmill. This study is the only known peer-reviewed research paper that directly investigated the effect of ROH on physiological measures in a human model. However, this analysis of the blade-ice interaction was limited to the characteristics of plastic ice and may not translate to real ice.

Further to the work cited above, preliminary investigations in our lab have suggested that variables that define the blade-ice relationship can be quantified and translated into a performance difference. Pilot studies investigated the independent effects of ROC and ROH on skating performance, while keeping other variables constant. The first study explored the relationship between ROC and aerobic on-ice performance in male, varsity hockey players ($n=20$). Players were asked to complete two on-ice tests of aerobic endurance [32]. During the first test, players skated on the contour of their choice and during the second, on a ROC customized for body weight. Each test was separated by a minimum of 48 hours of rest. Laboratory assessments of maximal oxygen consumption were also conducted corresponding to the two on-ice tests. Results revealed significant correlations between the on and off ice tests of aerobic endurance ($p \leq 0.05$) allowing us to believe that the on ice and off ice assessments were comparable. A repeated measures analysis of variance (ANOVA) indicated no significant difference between the pre- and post-intervention off-ice measures of maximum oxygen consumption ($p \leq 0.05$). However, a significant difference was found between the pre- and post-intervention on-ice measures ($p \leq 0.05$) suggesting an effect of the intervention. Significantly longer skating times and a higher measure of predicted on-ice VO_{2max} was achieved when subjects skated on the contour customized for body weight. These results indicated that contours adjusted by body weight allowed the player to skate longer with less fatigue.

The second study investigated the effect of ROH on anaerobic performance, specifically during the acceleration and stopping phases of an on-ice skating test, in male Junior B hockey players ($n=15$). Each participant completed an on-ice anaerobic performance test [Reed Repeat Skate (RRS)] on three separate days. For each on-ice test, the participant's skate blades were sharpened to one of three, randomly assigned, ROH values (0.63 cm, 1.27 cm, 1.90 cm). Performance times were recorded during each RRS and used to calculate anaerobic variables [anaerobic power (W), anaerobic capacity (W), and fatigue index (s, %)]. Each RRS was video recorded for the purpose of motion analysis. Video footage was imported into Peak Motus™ to measure kinematic variables of the acceleration and stopping phases. Variables calculated from the acceleration phase were: average velocity (m/s), (AV) over 6 m mean stride length (m) (SL), and mean stride rate (strides/s) (SR). Variables calculated from the stopping phase were: velocity at initiation of stopping (m/s) (IV), stopping distance (m) (SD), stopping time (s) (ST). A repeated measures ANOVA was used to assess differences in mean performance and kinematic variables across the three selected hollows. Further analysis was conducted to assess differences across and between trial by trial performance and kinematic variables for all hollows. The primary findings of the study suggest that skate blade ROH can have a significant effect on SL and SR during the acceleration phase and SD and ST during the stopping phase of an on-ice anaerobic performance test. During the acceleration phase, no significant difference was revealed in AV; however, significant differences were found in SR and SL across the three selected ROHs. Mean SR on the 1.27 cm hollow was significantly slower than on both the 0.63 cm and 1.90 cm hollows and SL was significantly longer when skating on the 1.27 cm hollow in comparison to the 1.90 cm hollow. During the stopping phase, stopping distance on the 0.63 cm hollow (4.12 m ± 0.14) was significantly shorter than on both the 1.27 cm hollow (4.43 m ± 0.08) ($p < 0.05$) and the 1.90 cm hollow (4.35 m ± 0.12) ($p < 0.05$). Mean ST was also significantly shorter when stopping on the 0.63 cm ROH than on either the 1.27 cm or 1.90 cm ROHs. Trial by trial results clearly illustrated the effect of fatigue on kinematic variables: AV, SR, IV decreased from Trial 1 to 6. Therefore, it appears that altering the skate blade ROH has significant and practical effects on accelerating and stopping performance.

From a practical perspective, both starting or acceleration techniques and stopping techniques changed when skating on less than optimal hollows. Players described the feeling of "spinning their wheels" on hollows that were too shallow and "ice bite" or "sluggish feet" when skating on hollows that were too deep. It also appears that an inverse relationship exists between ROH and body weight. For optimal on-ice performances, specifically for stops, starts and linear velocity to be achieved, lighter players preferred deeper hollows whereas heavier players performed best on more shallow grinds.

Mechanisms for Injury

Assuming that skate boots are properly fitted, and blade holder placement on the boot is optimized, the four sharpening characteristics will affect not only skating performance, but also potential for injury.

ROC defines how much of the blade length is in contact with the ice. A large ROC, putting more blade in contact with the ice, would potentially allow greater velocity during skating, but would make it more difficult for a player to pivot and change direction quickly. Having to overcome being "stuck" in the ice in this way could stress the lower extremity joint structures, especially the ligaments, and also the supporting musculature. Studies have shown that while heavier players can skate on a larger ROC, lighter players have difficulty controlling that much blade on the ice and prefer a smaller ROC.

ROH determines how deeply the blade edge bites into the ice. While a deep ROH has been shown to decrease stopping distance [33] constantly skating on a blade which is cutting deeply into the ice is fatiguing, especially for the muscle groups essential to the skating motion, such as the hip flexors and the adductor muscles of the inner thigh. Excessive muscle fatigue is a predisposing factor for muscle strains. Interestingly, players seem to intuitively understand this, as studies have shown that heavier players often prefer a shallower ROH, while lighter players choose a deeper ROH. Levelness of the blade edges is essential, no matter what the ROH, as unlevel edges can disrupt the normal pattern of ankle movements (plantar flexion+eversion) necessary for effective skating and also require more muscle activity to deal with the "chattering" of the blades over the ice.

The pitch of the blade will influence body alignment and especially affects the orientation of all of the joints in the lower extremity kinetic chain. For example, if the apex is located toward the front of the blade, the ankle will be positioned in dorsiflexion rather than in a neutral position, the plantar flexors will be continually on stretch and the knee will be flexed to keep the body's center of gravity balanced over its base of support. This may predispose the player to such injuries as Achilles' tendonitis, retrocalcaneal bursitis, or patellofemoral stress syndrome. The challenge to stay balanced in this position will also stress the muscles of the lower extremity and trunk.

Skate Sharpening as an Influence on Performance or Injury

It has been proposed that skate blade characteristics have the potential to affect a player's on-ice performance, including the ability to maintain balance, stability, and speed while in motion [7]. An optimum value for each of the four sharpening characteristics can produce more effective skating performances, whereas less than optimum values can result in negative effects. Being able to define blade characteristics and determine the best combination of ROH, ROC, and pitch for a specific player allows some degree of control in an environment which can often be unpredictable. The larger question is, what is the best combination? To date, weight and position or the technical demands on the player, have been the only two consistent variables that provide guidance in selecting the appropriate sharpening profiles or even understanding an athlete's preference in skate blade characteristics. For example, heavier weight players perform best on shallower ROH and longer ROC, whereas lighter weight players require deeper ROH and less blade length on the ice. The years of playing experience shared by the pros have allowed us to understand the dynamics associated with their preferences; however, more detailed guidelines need to be established for aspiring minor league players.

In a game that has several levels of management, all hopefully contributing to the success of the athletes, it is not uncommon to have difficulty pinpointing the cause of a problem, be it performance-related or injury-related. Athletes blame the skate sharpening, the sharpeners blame the ice, the ice management crew blames the pucks, etc. So it is imperative that all controllable factors contributing to the success of the athlete, including skate sharpening characteristics, be optimized. Managing the predictable measures such as sharpening variables may reduce the effect of the unpredictable parameters of the game, such as the ice surface.

Consistent efforts are needed to establish a mutually respectful relationship between researchers and practitioners, namely, the equipment managers/trainers, sharpening technicians, and players. It is anticipated that by strengthening these relations and establishing a better means of disseminating knowledge, players at all levels, from minor leagues to the pros, could be educated appropriately on the "science of skate sharpening."

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