Biomechanics of Power Skating: Past Research, Future Trends

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Skating is defined as the act of moving or gliding over ice while supported on steel runners attached to the boot or shoe. Over the past two centuries three separate and distinct forms of ice skating have evolved: Speed Skating, Figure Skating, and Power (or Hockey) Skating. Each has specific characteristics and requirements as defined by the events in which they take place. The purpose of this paper is to review the current knowledge of Power Skating and to project future trends in skating research in the sport of hockey.

Power skating involves several complex skills. These include: skating starts, full speed striding, stops, and backward skating. In addition, these skills must be integrated into the sport of hockey which requires rapid direction changes, skating curves, and stops and starts all while handling the puck, checking, or being checked. Thus, skating is a multi-faceted and highly complex motor skill.

Due to the nature of skating and the comparatively small numbers of subjects proficient in the skill, it has received less attention from sport scientists than most other forms of human locomotion. However, some valid information is available on skating starts, full speed skating, and backward skating. This includes both kinematic and kinetic data as well as information on the development of childrens' skating patterns. In addition, some work has been done on the effect of skate design on the mechanics of skating.

SKATING STARTS

The ability to start quickly from either a stationery or gliding position and reach a high velocity in a short time period is probably one of the most important skating skills in the game of hockey due to the confining nature of the ice surface area and the rapid movement of the puck. Research has shown that of the three most commonly used starting techniques, the front power start (Jones, 1969; Roy, 1978) and the side start (Thiffault, 1969; Roy, 1978) appear to be most advantageous for achieving high acceleration. It would appear that positive acceleration continues for at least the first 1.75 seconds of a skating start and that during this time a skilled skater can cover approximately 6.0 metres (Marino, 1979). Following this initial burst of acceleration it is likely that short periods of deceleration begin to appear in the kinematic pattern of the centre of mass due to the onset of a glide phase. It should be noted however that the net velocity value continues to increase well beyond the first few strides as it takes several strides and a considerable distance for a skater to reach full velocity.

Roy (1978) investigated the forces produced by the skate blade against a synthetic simulated ice surface affixed to a force platform during performance of the skating start. It was reported that the front style and the cross-over technique produced the highest impulse values in both the fore and aft and lateral directions.

The skating pattern most conducive to producing a rapid skating start has also been investigated. Correlation studies (Marino, 1983) and multiple regression analysis (Marino and Dillman, 1978) have indicated that, in general, the stride pattern which accompanies a high rate of acceleration and minimum skating time in a front start includes: a high stride rate, significant forward lean, a low push-off angle, and placement of the recovery skate almost directly below the hip joint on the recovery side rather than in front of the body at the touch down point following single support. This general pattern was confirmed by Greer, Dillman and Marino (1987) using similar modelling techniques. In addition, Roy (1978) and Marino (1975) have stressed that a proper application of lateral force is an important characteristic of both an effective start and of the full speed skating stride. Kirchner and Hoshizaki (1989a) investigated the role of the ankle during acceleration and determined that two main functions occur. For approximately 80% of the stride, the ankle undergoes dorsi flexion and pronation while the skater is gliding and then beginning the hip and knee extension of the thrust phase. The final 20% of the stride includes plantar flexion and supination of the ankle during the latter part of the thrust. Kirchner and Hoshizaki (1989b) also investigated the roll of the skate in moderating the range of motion at the ankle and found that removing ankle support did not significantly alter the basic displacement patterns although a larger range of motion was evident due to a greater plantar flexion and supination prior to toe off and greater pronation before heel off.

FULL SPEED SKATING

Although the importance of maximum velocity, straight line skating is not paramount in the sport of hockey, some research into this skill has been carried out. It has been reported (Marino and Weese, 1978) that highly skilled subjects reach maximum velocities in the range of 9.0 to 10.0 m/s. It is highly likely that elite skaters playing hockey in the National Hockey League would reach speeds in the range of 12.0 to 15.0 m/s. The attainment of velocities in this range, however, would be difficult due to the confining nature of most indoor ice surfaces and it is unlikely that velocities this high would occur during the normal course of a hockey game due to various other game requirements.

The basic skating pattern is closer to walking than to running in the sense that it involves two distinct temporal phases, single support and double support. It has been reported that in full speed skating the stride time is comprised of approximately 75 to 85 percent single support and 15 to 25 percent double support (Marino, 1977; Marino and Weese, 1978). Meuller (1972) speculated that the single support period was a glide phase and that propulsion took place during double support. The supporting data, however, were taken on speed skaters. Marino and Weese (1978) investigated the kinematic patterns of the centre of mass of highly skilled skaters and reported that thrust begins well before the recovery skate touches down and continues throughout the remainder of the single support phase and through the double support phase. Thus, there appears to be three functional phases in full speed skating: glide during single support, thrust during single support, and thrust during double support.

As with all forms of human locomotion, forward progression on ice skates depends on the cyclic motion of the contralateral limbs to form a movement cycle. The velocity of movement is determined by a combination of the rate of striding times the length of each stride. It has been reported (Marino, 1977) that changes in velocity are due almost exclusively to changes in stride rate and that at all velocities stride length is approximately the same. In fact, at very high velocities there is a slight decrease in the mean stride length. These relationships are different than those known to occur for running and can be attributed to the presence of glide in the ice skating stride. At lower velocities, the skating movement pattern includes a long, leisurely glide phase. As the force of the thrust increases, the time of the stride decreases but a similar glide length occurs due to the larger thrust. Thus, the relationship between velocity and stride rate has been found to be statistically significant ($r = .76$, $p < .05$) while no significant relationship has been found between stride length and velocity ($r = .05$). These results were reported in a design that included skating velocity (3 different levels) as an independent variable (Marino, 1977).

Investigations comparing skilled to less skilled skaters have focused on several features. Page (1975), for example, stated that high velocity was partly a function of the creation of high angular velocities in the lower limb joints during the thrust phase. The knee was cited as being particularly important. In addition, a large range of motion at the knee was also found to correlate highly with skating velocity. McCaw and Hoshizaki (1987) confirmed these findings and suggested that the greater range of motion evident at both the hip and knee of faster skaters would serve to increase the impulsiveness of the thrust against the ice. They also indicated that an eccentric motion prior to extension of these two joints is one possible cause of the larger impulse.

Little evidence exists of efforts to investigate the kinetics of ice skating. The complexity of measuring ice reaction forces mitigates against replication of similar studies of walking and running. However, some research has been carried out to look at segmental mechanics of skaters under varying conditions of fatigue using an inverse dynamics approach on the free swinging segments (Marino and Potvin, 1989). It was determined that as skaters went from a condition of non-fatigue to a state of anaerobic fatigue during approximately 45 seconds of high intensity skating, the peak net muscle moments at the knee joint of the non-support leg decreased significantly. In addition, the peak power measured at the knee of the swinging leg also decreased significantly as the skaters became fatigued (Marino and Potvin, 1989). In another investigation, a segmental work-energy assessment of skaters performing at different levels of fatigue was undertaken (Marino and Goegan, 1990). It was reported that the decreasing velocity evident as fatigue increased had little effect on the absolute energy values of the body modeled as a thirteen segment linked system. Also, the absolute values of energy transferred between and within segments was unaffected. However, when the rate of both work and energy exchange were measured, it was found that fatigue and lower velocity did significantly decrease both of these variables. It was concluded that efficient energy utilization by highly skilled subjects is sensitive to velocity changes accompanying fatigue.

BACKWARD SKATING

Backward skating is a skill required by defensemen in hockey. There are two common forms of backward skating: the C-cut and the cross-over. Each is used depending on game requirements. Backward skating has received scant attention from researchers. However, Marino and Grase (1993) did investigate selected mechanics features of the backward C-cut skating stride. Ten highly skilled subjects were selected and an overhead filming protocol was used to measure several basic movement characteristics. It was reported that maximum backward velocity was approximately 82% of maximum forward velocity. In addition, there was a strong correlation between forward and backward skating velocity ($r = .81, p < .05$). The mean backward velocity was 6.57 m/s and was comprised of a cycle rate of 1.16 cycles per second and a cycle length of 5.65 m. No significant differences were reported between left and right strides indicating equal contributions from each side of the body. It was concluded that backward skating is a symmetrical movement pattern and that faster backward skaters have lower cycle rates, longer cycle lengths and wider cycles than slower backward skaters.

OTHER SKILLS

Unlike other forms of locomotion, power skating has not been the topic of extensive research. Even other types of ice skating have received more attention in recent years. For example, speed skating, an olympic sport, has been the topic of several investigations of starting, full speed striding and curve skating. Since the requirements of speed skating are fairly standardized it is relatively easy to design experiments to look at its various skill components. Similarly, researchers have begun to look more carefully at figure skating skills. Here again, the sport consists of several pre-planned and pre-practised components linked into a complete program. Each of those components can be isolated, broken down and studied. Unfortunately, the nature of the game of hockey requires constant change and innovation in the skating patterns and it is difficult to isolate particular skills that are practised repeatedly. This fact has been reflected in the somewhat limited approach to power skating research. Due to the complexity of the movement patterns involved and the perceived difficulty of overcoming the limitations of conducting research in a sport with relatively few skilled subjects and limited facilities, several aspects of power skating have received no attention from biomechanics researchers. Skating stops and direction changes are important skills in hockey which have not been studied scientifically. Also, no evidence can be found on skating curves on hockey skates although speed skating analysts have looked at this skill in the sport of speed skating. Finally, all of the skills of hockey such as shooting, passing, stick handling, and checking have to be performed while skating and very few attempts have been made to link aspects of skating ability with proficiency in executing these skills. Another whole line of investigation is also on the horizon with the burgeoning popularity of in-line skating and roller hockey. Whether the information on ice skating can be applied to roller skating remains to be seen. Certainly, the larger rolling frictional forces between in-line skates and the supporting surface present a major difference between ice and in-line skating. Another totally different skill is stopping in as much as in-line skates can not be unweighted and turned at a 90 degree angle to the surface as easily as ice skates can. Thus, much work remains to be done in the whole area of in-line roller skating.

FUTURE CONSIDERATIONS

The history of research on power skating has seen sporadic attempts by several biomechanics researchers to investigate the mechanics of the skating pattern. Although a few of the power skating skills such as starting and full speed striding have received considerable attention, much remains to be done to further the knowledge of these complex skills. In addition, several of the skills employed by skaters in the game of hockey have received no attention from the scientific community. Based on a review of past research and current knowledge it would appear that several areas of interest are ripe for future investigation. These would include, but not be limited to, the following:

1. More precise kinetic information on starting is required. This would include not only detailed analysis of "ice" reaction forces, but also segmental analysis to determine the nature of the various contributions of the joints to power and force production.

2. Further kinetic analysis of the functional phases of full speed striding is necessary. While recent work on energy utilization during fatigued performance is interesting, little evidence exists of efforts to fully understand the nature of the segmental relationships in force production and maintenance of a maximum skating velocity.

3. The mechanics of backward skating are just beginning to be understood. Since the thrust and glide motion is not like that of forward skating, methods have to be devised to measure the magnitude and especially the direction of the forces producing the motion. It would appear from the movement pattern itself that much of the thrust occurs in a sideways direction and that the use of a cross-over technique, especially in starting in a backward direction, might be advantageous. This conclusion, however, must await a significant amount of future study.

4. Stopping is an important skill in the sport of hockey both from a performance as well as a safety standpoint. At present, no evidence exists of efforts to analyze stopping and this is an area which deserves attention from biomechanists in the future.

5. The complex nature of ice hockey requires almost constant direction changes and frequent periods of skating curves all while performing the other sport related offensive and defensive skills. Performance of these skating movements in the context of the game of hockey are currently understood from only the qualitative, subjective point of view. They require scientific investigation to broaden the knowledge of players and coaches and to propose practice and training strategies to enhance performance.

6. In-line, roller skating is a rapidly expanding sport both from a recreational as well as a competitive perspective. At present, little evidence exists of scientific study of this skill. The degree of transfer from ice to roller skating is questionable due to the different nature of the contacting surfaces. Future research should look at the surface - roller interaction and its effect on performance. Also, the mechanics of starting and stopping on in-line skates needs to be studied in order to create teaching and practice strategies for

teachers and coaches in this variation of the sport of skating.

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