The Effects of Anaerobic Fatigue on Biomechanical Features of the Ice Skating Stride

G. Wayne Marino
James Potvin
Department of *Kinesiology*
University of *Windsor*
Windsor, Ontario N9B 3P4
Canada

INTRODUCTION

Both anaerobic and prolonged aerobic activity produce fatigue in athletes. Apart from the obvious effects on physiological endurance, fatigue may also result in significant changes in performance technique. The effects of fatigue on mechanics of various sports skills have been studied by a number of biomechanists. With reference to human locomotion, most research appears to have considered the effects of fatigue on running mechanics.

Adrian and Kreighbaum (1973) studied the running characteristics of participants in a twenty-four hour relay marathon. Although runners were found to vary in their response to fatigue, it was reported that a state of fatigue resulted in smaller muscle torques being applied to the shank during the running movement pattern. Bates and Haven (1984) studied the temporal and kinematic characteristics of the female running pattern under conditions of non-fatigue and fatigue. It was found that fatigue was associated with both lower velocities and shorter strides. Elliott and Roberts (1981) studied stride characteristics occurring at various points in a 10,000 m race. They also reported significant decreases in both running velocity and stride length with the onset of fatigue. In addition, it was found the relative velocity of the ankle in the backward direction prior to foot strike was lower during the later stages of the race.

Although no specific data were cited, Lagasse (1979) hypothesized changes in the biomechanics of hockey skills under conditions of fatigue. This speculation was based on previous theoretical research dealing with the response characteristics of fatigued muscle as well as more applied research into the effects of fatigue on other gross motor skills. Greer and Dillman (1984) looked at the effects of fatigue on selected kinematic features of the ice skating strides of sixteen elite hockey players. Results indicated that both single and double support times increased with fatigue, resulting in a lower stride rate. Also, the time to skate 23.4 m during each of the lengths of the ice covered increased significantly as the skaters tired. There were also several significant changes reported in both absolute angles at the knee and relative angles of the trunk and leg at strategic points during the stride.

In summary, a case can be made, based on limited research on skating and more extensive work on running, that biomechanical characteristics of the ice skating stride are affected by fatigue. However, it appears that a good deal of work remains to be done before the precise changes are understood. Specifically, there is little or no evidence of attempts to identify changes in the kinetic properties of ice skating accompanying the onset of fatigue.

The purpose of this study was to investigate differences in both the basic stride characteristics and selected kinetic variables which accompany various levels of fatigue created by prolonged, high output, anaerobic work. Specifically, rates and lengths of striding as well as lower limb energy outputs, swing leg muscle torques and power were measured under both non-fatigued and fatigued conditions.

METHODS

Seventeen elite performers were selected as subjects. All were participants in ice hockey at the Major Junior level and ranged in age from seventeen to twenty years old. Prior to analysis, two of the subjects were eliminated resulting in a final subject pool of fifteen.

The anaerobic capacity test of Lariviere and Godbout (1976) was selected as the skating task to be completed by each subject. Briefly, a subject started from a standing position, skated 30 m, stopped and returned. This procedure was repeated five more times (for a total of sixrepetitions) non-stop.

A Locam camera set to operate at 100 fps was strategically placed to record a side view of each skater. The camera was set in a position to record two full strides near the end of a length (to ensure as high a velocity as possible) hut far enough from the end to avoid recording a period of deceleration leading to the stop. Filmed records were taken of the portion of the first, fifth and sixth repetitions. This ensured assessment of one non-fatigued trial and two others at progressively higher fatigue levels.

Film analysis was facilitated through use of a Vanguard projector, and an Amtek AC30 digitizer interphased with an Apple II microcomputer. Coordinate data were recorded for each frame of film from the point of pushoff of the toe to the subsequent pushoff of the toe of the same leg. Thus, each cycle consisted of two periods of single support, each followed by a period of double support. Data were collected for the greater trochanter at the hip, the lateral epicondyle of the disal femur of the knee, the lateral malleolus at the ankle, the heel, and the fifth metatarsal-phalangeal joint.

Raw data were smoothed using a Butterworth fourth-order, low pass digital filter. The cutoff frequency was 5 Hz for the hip and knee markers and 6 Hz for the ankle, heel and metatarsal-phalangeal joint. In addition to the actual frames of interest, data were entered for ten frames before and after the stride to ensure accurate estimates of the real life segment locations.

Smoothed data were entered into an appropriate dynamics software package and calculations of basic stride characteristics and selected kinetic features were completed. These kinetic properties included net muscle force moments and power at the knee and total mechanical energy of the thigh and lower leg.

The independent variable was fatigue as represented by trial number. Each 60 m distance (30 m and return) was considered a trial. The first trial was considered non-fatigued. The fifth and sixth were assumed to be completed in a fatigued condition. Thus, there were three levels of the independent variable. Seven dependent variables were measured. These included:

- skating velocity
- cycle length
- cycle rate
- peak force moments at the knee
- peak power at the knee
- peak energy of the thigh
- peak energy of the lower leg

Each dependent variable was subjected to a one-way analysis of variance (ANOVA) with repeated measures to assess the statistical significance of between trial differences. Where appropriate, a Neuman-Keuls post-hoc, multiple comparisons analysis was used to further clarify the differences.

RESULTS AND DISCUSSION

Three levels of the independent variable fatigue were represented by trials one, five and six of a continuous, maximum effort skating task. Both kinematic and kinetic aspects of the movement were measured.

Basic characteristics of the skating cycle are presented in Table 1.

Table 1

Means of Skating Cycle Kinematics Under Three Conditions of Fatigue N = 15

		Non-Fatigued	Fatigued	
		Trials	Trials 5	Trials6
Skating Velocity*	x	6.66	5.55	5.64
(m/s)	S	.61	.58	.61
Cycle Length	x	4.76	4.83	4.87
(m)	S	.65	.91	.82
Cycle Rate*	x	1.40	1.15	1.16
(c/s)	S	.12	.13	.17

*Significant Between Trial Differences at $P < .05$.

The mean skating velocity in the non-fatigued trial was 6.66 m/s. This was found to be significally high (P .05) than the velocities recorded under each of the fatigued condition (5.55 m/s and 5.64 m/s). These differences in velocity were accompanied by significant decreases in the rate of striding (P .05) as indicated by the cycle rates under non-fatigued (1.40 c/s) and fatigued (1.15 c/s and 1.16 c/s) conditions. No significant differences in cycle length were found as fatigue increased. Thus, it appears that the decreases in velocity which occur as a skater tires are due primarily to a slower rate of movement. In addition, it is evident that the longer cycle time allowed the subjects to utilize the glide phase of the skating pattern to achieve fairly consistent cycle lengths even under conditions of fatigue.

To further investigate mechanical changes occurring with the onset of fatigue, kinematic data were combined with inertial parameters to estimate net force moments and power at the knee joint during the swing phase of the leg motion. Also, potential, kinetic and rotational energies of the thigh and lower leg were determined at each frame of film and combined to provide a total mechanical energy value.

Peak muscle force moments and power at the knee are listed in Table 2.

Table 2

Mean Peak Net Muscle Force Moments and Power at the Knee of the Swing Leg Under Three Conditions of Fatigue
N = 15

		Non-Fatigued	Fatigued	
		Trial **1**	Trial **5**	Trial **6**
Peak Net Muscle Force Moments at the Knee* (N-M)	x	**31.7**	**23.2**	**23.5**
	S	**7.7**	**6.1**	**5.6**
Peak Power at the Knee* (J/S)	x	**245.2**	**164.9**	**160.03**
	S	**64.5**	**41.7**	**44.3**

* Significant Between Trial Differences at $P < .05$.

It is evident that both variables decreased significantly ($P < .05$) as fatigue developed. To should be noted that the values for both moments of force and power are relatively low. This is probably due to the passive nature of the recovery phase of the stride and the fact that only sub-maximal effort is required to move the leg forward in preparation for the subsequent stride. It is anticipated that significantly higher values would be recorded for the same leg during the propulsive phases when the foot is contact with the ground.

Peak total energy values of the thigh and lower leg (shank) are listed in Table 3.

Table 3.

Mean Peak Total Energy Values of the Thigh and Lower Leg Under Three Conditions of Fatigue
(N = 15)

		Non-Fatigued		Fatigued
		Trial 1	Trial 5	Trial 6
Peak Energy of the Thigh* (J)	x	480.6	414.8	421.0
	S	64.3	60.3	64.3
Peak Energy of the Lower Leg* (J)	x	270.6	221.1	226.4
	S	41.6	36.3	39.2

*Significant Between Trial Differences at P c .05

ANOVA revealed that both thigh and shank peak energies decreased significantly (P c .05) from Trial 1 to both Trials 5 and 6. There were no significant differences between Trials 5 and 6. Since energy depends on both fixed and inertial properties such as mass and moment of inertia, and variable values such as height and velocity, it is apparent that energy changes reflect decreased velocity of segmental movements. The deterioration in peak energies as fatigue increases would naturally occur as a result of the lower muscle forces and power previously discussed and illustrated in Table 2.

SUMMARY AND CONCLUSIONS

Of particular note is the fact that the only significant differences found in this study occurred between Trial 1 (non-fatigued) and both Trials 5 and 6 (fatigued). None of the dependent variables showed significant differences between Trials 5 and 6. It took, on average, about 45 to 50 seconds for the subjects to complete the total task. Thus, it is evident that significant changes in skating technique had occurred after 30 s of continuous maximum effort skating. These results point out the importance of relatively quick personnel changes during periods of high intensity, non-stop motion. The consequence of fatigue as reflected in the lower torque, power and energy values are that players are not able to move as fast. This certainly has implications for effective performance in ice hockey. Of possibly even greater significance is the potential for injury. If a player's movement is slower in a fatigued condition, it may be more difficult to stop or change directions, thereby avoiding collisions with other players, goalposts on the boards surrounding the ice surface.

At the present time, a more detailed work-energy analysis of the skating movement pattern is underway. It is anticipated that the results of the ongoing work will further clarify changes occurring with fatigue by identifyiig specific segmental energy deterioration as well as variations in the ability to passively exchange energies both within and between segments.

In summary, this study has identified several specific changes in skating mechanics which accompany increased fatigue. These changes in variables, which include thigh and shank segmental energies, recovery phase knee torques and power, and skating velocity and cycle rate, occur by about the 30 second mark in a continuous, maximum effort skating task. It is suggested, therefore that rapid deployment of fresh personnel would be advantageous in periods of similar levels of activity during ice hockey competition.